UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Escola Superior d'Agricultura de Barcelona

TECHNICAL – ECONOMIC STUDY ON IMPLEMENTING A BIOGAS PLANT OPERATING WITH GREENHOUSE VEGETABLE WASTE GENERATED IN THE REGION OF ALMERIA

Final Degree Project

Biosystems Engineering

Author: Pablo Calbo Antolino

Tutor: Xavier Flotats

Date: January 18th, 2018

Preface

This research represents the culmination of a work that has taken place within the period from September 2016 to December 2017. The experimental work of this dissertation has been conducted in the Eco-technology laboratory of the Institute of Biosystems at Poznan University of Life Sciences, Poland.

The scientific team of the Eco-technology laboratory of Poznan is established by PhD students, master degrees students and technics of laboratory. The team is currently conducting many researches and they have many arrangements with companies with comprehensive preparation of investment related to biogas plants and peripheral installations connected with using electricity, heat, digested and CO_2 from flue gas.

The motivation for carrying out this work stems from the idea of working in a project and a research which could be useful to the organic waste treatment industry in Spain. Upon the research of several locations on organic waste treatment in Catalonia, including, for example, treatment of both sewage and organic residues from slaughterhouses, finally the huge biomass potential from greenhouse vegetable waste from the region of Almeria met my demands.

Furthermore, the assumption of having to my disposal the biggest polish biogas laboratory to conduct the tests as well as already filed data sheets made this project option more encouraging and appealing. New innovative an advanced technologies for organic waste treatment and especially for agricultural waste has been developed at present by polish researchers alongside with a Swiss company and it opens the possibility to introduce new alternatives to Spanish biogas market.

Nonetheless, further than the initial motivation, I must acknowledge that during the execution of the experiments my inability to collect vegetable samples as well as the appearing of some technical setbacks discouraged me slightly to face the writing of the memory and the results.

The dissertation is structured with a short summary (English, Spanish and Catalan), followed by an introduction, objectives, methodology and a theoretical framework at the beginning and continuing with the body of the drafted containing the heavy development of the research/project.

Financial support

The research of this thesis has been financially supported by the Eco-technology laboratory at Poznan University of Life Sciences belonging to the Biosystems Institute of the Agronomy and Bioengineering department.

Acknowledgments

Thanks to Prof. Dach for his kindness, understanding, help and valuable comments and knowledge provided in the preparation of this work;

Thanks to colleagues from the laboratory of Eco-technology for help me and teach me with the implementation of the work;

Thanks to Prof. Flotats for his help, patience and valuable comments and knowledge provided in the preparation of this work;

Mandatory page

Title: Technical – economic study on implementing a biogas plant operating with greenhouse vegetable waste generated in the region of Almeria.

Name Bachelor's degree student: Pablo Calbo Antolino.

Name and title of supervisor or any other supervisor:

Professor **Jaceck Dach**, Institute of Biosystems, Poznan University of Life Sciences, Wojska Polskiego 42, 60-628 Poznan, Poland.

Associate Professor **Andzrej Lewicki**, Institute of Biosystems, Poznan University of Life Sciences, Wojska Polskiego 42, 60-628 Poznan, Poland.

Professor **Xavier Flotats**, Agro-Food Engineering and Biotechnology department at UPC BarcelonaTECH, Esteve Terradas, 8, 08860 Castelldefels, Barcelona, Spain.

Conference participation:

Oral Biogas plant exploitation under the low-subsidies market conditions: maize silage vs biowaste scenarios. Jacek Dach, Krzisztof Jozwiakowski, Alina Kowalczyk-Jusko, Kamil Kozlowski, Maciej Neugebauer, Pablo Calbo. Poznan university of Life Sciences, Poland. 16th International Multidisciplinary scientific Geoconference SGEM 2016, Viena, November 2016.

Abstract

The work developed so far has shown that in the complex of greenhouses in the Region of Almeria more than 2 million of tons of vegetable waste are generated annually, whose destination is composting in piles for the production of biofertilizer in greater measure, providing a minimum economic value.

The present work includes experiments of energy valorization of these by-products in order to verify that there is a big potential for generating both electric and thermal energy based on biogas. In net terms, the results show that can be generated around 102,23 GWh/year and 122,68 GWh/year respectively, which translates into an installed power of 12,47 GW and 14,96 GW.

The main objective of the project is to determine the technical-economic viability of the valorization of these plant remains through the installation of a biogas plant. In addition, a biofertilizing product is acquired and the CO_2 from the flue gas is recovered to enrich the crops of the adjacent greenhouses and to be sold at better prices than the current ones. From this arises the opportunity to solve the existing problem of demand for the appearance of new treatment facilities for these agricultural residues as well as to valuing them more efficiently obtaining more income from the same input base. For these reasons, thanks to biogas, the agricultural waste that is currently a problem for the farmer becomes a source of multiple benefits.

The design of the project contemplates the construction of a biogas plant on Dynamic Biogas technology (full mix reactor without recirculation), which is the most suitable for the selected substrates. For an optimal functioning of the plant with a hydraulic retention time estimated of 40 days and for a volume of 2.000 m^3 of digesters, 17.083 Mg of waste will be treated annually. As a result, a plant with a firm electrical power of 107 KW is obtained as well as 3.840 GJ of thermal energy from cogeneration. Besides, the digestate annually produced would replace 20% of the whole current demand of fertilizers in the greenhouses.

In regards to the economic evaluation, with an investment of 2,3 million euros, a net present value of – 1,09 million euros and an internal rate of return of 2,26% is obtained. Through the sale of electric energy, thermal energy, biofertilizer, CO_2 and carbon credits, approximate revenues to 274 thousand euros/year are obtained. On the other hand, the expenses and costs

represent a sum around 113 thousand euros/year. The amortization is covered at 20 years, which is the lifetime of the installation and leaves the project with little slack.

The viability of the project cannot be assured not only due to the negative results of the economic evaluation but also because of the risks involved in the installation site and the transmission costs - ensuring the sale of thermal energy is very important -. In addition, an investor will always look for projects with higher internal rates of return, for which the government has a fundamental role: to propose clear economic incentives for investors to decide to invest in this type of energy projects.

Resum

Fins al moment, el treball desenvolupat ha posat de manifest que en l'explotació del complex d'hivernacles del Ponent d'Almeria es generen més de 2 milions de tones anuals de residus vegetals, els quals es destinen al compostatge en piles per a la producció de biofertilitzant en major mesura, aportant un valor econòmic mínim.

El present treball inclou experiments de valorització energètica d'aquests subproductes amb l'objectiu de comprovar que hi ha un gran potencial de generació tant d'energia elèctrica com tèrmica basant-se en biogàs. En termes nets, es poden generar al voltant de 102,23 GWh/any i 122,68 GWh/any respectivament, la qual cosa es tradueix a unes potències instal·lades de 12,47 GW i 14,96 GW.

El projecte té com a objectiu principal determinar la viabilitat tecnicoeconòmica de la valorització d'aquestes restes vegetals mitjançant la instal·lació d'una planta de biogàs. A més, s'adquireix un producte biofertilitzant i es recupera el CO_2 dels gasos de combustió per enriquir els cultius dels hivernacles adjacents i per ser venuts a millors preus que els actuals. A partir d'això sorgeix l'oportunitat de resoldre el problema existent de demanda d'aparició de noves instal·lacions de tractament d'aquests residus agrícoles a més de valorar-los de manera més eficient obtenint majors ingressos amb la mateixa base d'entrades. Per aquestes raons, gràcies al biogàs, els residus agrícoles que actualment són un problema per l'agricultor es converteixen en una font de múltiples beneficis.

El disseny del projecte contempla la construcció d'una planta de biogàs tecnologia Dynamic Biogas (reactor de mescla completa sense recirculació), que resulta ser la més adequada per als substrats seleccionats. Per a un òptim funcionament de la planta amb un temps de retenció hidràulica estimat de 40 dies i per a un volum de 2.000 m^3 de digestors es podran tractar 17.083 Mg de residus anualment. Com a resultat s'obté una planta amb una potència elèctrica ferma de 107 KW a més de 3.840 GJ d'energia tèrmica per co-generació. A més, el digerit produït anualment reemplaçaria el 20% de la demanda actual total de fertilitzants als hivernacles.

Pel que fa a l'avaluació econòmica, amb una inversió de 2,3 milions d'euros, s'obté un valor actual net de – 1,09 milions d'euros i un taxa interna de retorn de 2,26%. A través de la venda d'energia elèctrica, energia tèrmica, biofertilitzant, CO_2 i crèdits de carboni s'obtenen ingressos aproximats a 274 mil euros/any. D'altra banda, les despeses i costos representen una

suma al voltant de 113 mil euros/any. L'amortització es cobreix als 20 anys, la qual cosa és la vida útil de la instal·lació i deixa el projecte amb poca folgança.

No es pot assegurar la viabilitat del projecte no només a causa dels resultats negatius de l'avaluació econòmica sinó també pels riscos que impliquen el lloc d'instal·lació i els costos de transmissió - assegurar la venda d'energia tèrmica és molt important -. A més, un inversor sempre buscarà projectes amb taxes internes de retorn més altes, per la qual cosa el govern té un paper fonamental: el de proposar incentius econòmics clars perquè els inversors decideixin invertir en aquest tipus de projectes energètics.

Resumen

Hasta el momento, el trabajo desarrollado ha puesto de manifiesto que en la explotación del complejo de invernaderos del Poniente Almeriense se generan más de 2 millones de toneladas anuales de residuos vegetales, cuyo destino es el compostaje en pilas para la producción de biofertilizante en mayor medida, aportando un valor económico mínimo.

El presente trabajo incluye experimentos de valorización energética de dichos subproductos con el objetivo de comprobar que existe un gran potencial de generación tanto de energía eléctrica como térmica en base a biogás. En términos netos, se pueden generar alrededor de 102,23 GWh/año y 122,68 GWh/año respectivamente, lo cual se traduce a unas potencias instaladas de 12,47 GW y 14,96 GW.

El proyecto tiene como objetivo principal determinar la viabilidad técnico-económica de la valorización de dichos restos vegetales mediante la instalación de una planta de biogás. Además, se adquiere un producto biofertilizante y se recupera el CO_2 de los gases de combustión para enriquecer los cultivos de los invernaderos adyacentes y para ser vendidos a mejores precios que los actuales. A partir de esto surge la oportunidad de resolver el problema existente de demanda de aparición de nuevas instalaciones de tratamiento de estos residuos agrícolas además de valorarlos de manera más eficiente obteniendo mayores ingresos con la misma base de insumos. Por estas razones, gracias al biogás, los desechos agrícolas que actualmente son un problema para el agricultor se convertirían en una fuente de múltiples beneficios.

El diseño del proyecto contempla la construcción de una planta de biogás tecnología Dynamic Biogas (reactor de mezcla completa sin recirculación), que resulta ser la más adecuada para los sustratos seleccionados. Para un óptimo funcionamiento de la planta con un tiempo de retención hidráulica estimado de 40 días y para un volumen de 2.000 m^3 de digestores se podrán tratar 17.083 Mg de residuos anualmente. Como resultado se obtiene una planta con una potencia eléctrica firme de 107 KW además de 3.840 GJ de energía térmica por co-generación. Finalmente, el digerido producido anualmente reemplazaría el 20% de la demanda anual total de fertilizantes en los invernaderos.

En cuanto a la evaluación económica, con una inversión de 2,3 millones de euros, se obtiene un valor actual neto de – 1,09 millones de euros y una tasa interna de retorno de 2,26 %. A través de la venta de energía eléctrica, energía térmica, biofertilizante, CO_2 y bonos de carbono

se obtienen ingresos aproximados a 274 mil euros/año. Por otra parte, los gastos y costos representan una suma alrededor de 113 mil eur/año. La amortización se cubre a los 20 años, lo cual es la vida útil de la instalación y deja el proyecto con poca holgura.

No se puede asegurar la viabilidad del proyecto no solo debido a los resultados negativos de la evaluación económica sino también por los riesgos que implican el lugar de instalación y los costos de transmisión - asegurar la venta de energía térmica es muy importante -. Además, un inversionista siempre buscará proyectos con tasas internas de retorno más altas, por lo cual el gobierno tiene un rol fundamental: el de proponer incentivos económicos claros para que los inversionistas decidan invertir en este tipo de proyectos energéticos.

Table of contents

List of signs

- GVW – greenhouse vegetable waste
- RES – renewable energy sources
- REG – renewable energy generation
- GHG – greenhouse gas
- ODM – organic dry matter
- FM – fresh matter
- DM – dry matter
- TS – total solids
- VS – volatile solids
- M – mass of the substrate [Mg]
- My – mass of the substrate needed to supply the biogas plant for a year [Mg]
- S – area of the greenhouses [ha]
- Gp – yield of the greenhouses [$Mg \cdot ha^{-1}$]
- Vb – volume of produced biogas [m^3]
- Eb – biogas production efficiency [$m^3 \cdot Mg^{-1}$]
- VCH4 – volume of produced methane [m^3]
- [CH4] – methane content [%]
- V_TCH4 – the total volume of the produced methane [m^3]
- VCH41 – the volume of methane produced by the susbtrate 1 [m^3]
- VCH42 – the volume of methane produced by the substrate 2 [m^3]
- VCH4n – the volume of methane produced by the substrate n [m^3]
- MCO2 – mass of carbon dioxide produced after combustion [Mg]
- Em – methane production efficiency [$m^3 \cdot Mg^{-1}$]

- Ee – quantity of electricity produced in cogeneration [MWh]
- Et – the amount of heat produced in cogeneration [MWh]
- ReCH4 – energy efficiency coefficient of methane [0,00917 MWh · m^{-3}]
- ηe – electrical efficiency of cogeneration unit [-]
- ηt – thermal efficiency of cogeneration unit [-]
- Et [GJ] – quantity of produced thermal energy expressed in [GJ]
- Et [MWh] – quantity of produced thermal energy expressed in [MWh]
- Pe – electric power [MW]
- Pt – thermal power [MW]
- t – time work of cogeneration unit [h], ~ *8200 [h]*
- HRT – hydraulic retention time [days]
- CF – correction factor [-]
- HRT_I – ideal hydraulic retention time [days]
- TF – treatment flow [m^3/day]
- VD – volume digesters [m^3]
- P – annual gross profit exploitation of biogas plants [EUR]
- AR – annual income in respect of the biogas plant operation [EUR]
- AC – annual operating costs of biogas plants [EUR]
- ARee – annual income from the sale of electricity [EUR]
- ARet – annual income from the sale of thermal energy [EUR]
- pt – price for thermal energy [EUR· GJ^{-1}]
- ARpp – annual income from the sale of fertilizers [EUR]
- ARCO2 – annual income from the produced carbon dioxide [EUR]
- ARcc – annual income from carbon credits [EUR]
- pcc – selling price of carbon credits = 5 [EUR · Mg^{-1}]
- pe – estimated selling price of electricity for the year 2018 = 52 [EUR · MWh^{-1}]

- ARet – annual income for the produced thermal energy [EUR]
- ηep – energy efficiency furnace [-] *in the present case is 0,6*
- Md – mass of produced of digestate [Mg]
- pd – selling price of the digestate [EUR · Mg^{-1}]
- ηf – weight maintenance factor in the fermentation [-], *we must accept a value in the range 0,90 – 0,93.*
- Vbh – volume of biogas consumed within 1 hour of work [$m^3 \cdot h^{-1}$]
- tCO2 – number of annual hours per day of pumped CO2 in a greenhouse [h]; *typically, an average of 8 h/day for 10 months, giving 2400 h*
- ϱCO2 – density of CO2 0,001842– 0,001977 [Mg m^{-3}]
- CCO2 – unit price used in greenhouses as CO2 [EUR · kg^{-1}]
- C_{abi} – cost of biogas installation [EUR]
- Csubr – cost of substrates [EUR]
- Cop –cost of operation [EUR]
- Cserv – cost of services [EUR]
- Cdepr – cost of depreciation [EUR]
- Cstaff – cost of staff [EUR]
- Cusubr – the unit price of the substrate [EUR · Mg^{-1}]
- CT – the cost of transport of substrate [EUR]
- CSM – the cost of storage and management [EUR]
- Cserv – service cost [EUR]
- Cms – maintenance service cost [EUR]
- Ctechs – technological service cost [EUR]
- Cinst – cost of biogas installation [EUR]
- Ee – amount of electricity produced [MWh]
- Rtech – technological cost ratio [EUR · MWh^{-1}]

- Nstaff – number of employed persons [-]
- Sg – average annual gross salary of the employees [EUR]
- NPV – net present value
- N – number of years of plant life
- I – investment cost
- CF_n – net cas flow in year N
- IR – interest rate - *in the present case is 0,1*
- IRR – internal rate of return
- MYR – minimum yield required
- RD – risk differential

1. Introduction

The project focus on the process of anaerobic digestion of agricultural waste from intensive farming in greenhouses developed in recent years in the Province of Almeria, and the work carried out so far has shown that more than 2 million of tons of organic waste are generated every year in this region. At present, part of these wastes are already treated and used for the generation of compost, but there is no demand high enough to eliminate all of them, so they are being accumulated generating a significant environmental impact in the area and barely economically contributing to either farmers or companies.

The use of this biomass for energy uses represents an alternative route to the current electric model and has certain advantages over it.

- Neutral balance of GHG emissions in the atmosphere.
- Biogas is a renewable alternative fuel whose production source is inexhaustible.
- Streamlining the activity of local territories through the use of their own resources.
- Generation of jobs committed to society and the environment.
- Reduction of energy dependence of the territory.
- To undoing of agricultural residue and its economic valorization.

Through this project is intended to put in value the potential that they have as a renewable energy source and as an agricultural biofertilizer thus aiming to evaluate whether the implementation of a greenhouse – biogas plant system in the Almeria Province is technical and economic feasible.

The general and specific objectives and the methodology carried out are explained in the following sections.

For the development of all this work has been carried out an extensive bibliographical work, using resources from different public entities, both at European level, National and Autonomous, companies specialized in the sector and studies in different fields on anaerobic digestion. For this has been consulted available literature, project reports and writers of biogas projects (professors and lab mates).

Finally, this project will lead us to conclusions and future lines of research that will try to improve the current waste management of this study.

2. Objectives

The main purpose of this project is to conduct both a technical and economic evaluation of a biogas plant built and connected with a type-scale modern greenhouse producing vegetables, exclusively in base of the results obtained subjecting samples of GVW to biogas production experimental tests.

The general objectives can be listed below:

- Evaluate the energy potential of the GVW in the Almeria region in terms of both biogas (and methane) and power capacity;
- Perform a technical analysis of the power biogas plant, considering from construction aspects to aspects related to energy production during the evaluation period.
- Perform an economic analysis of the installation, ranging from the business model to a sensitivity analysis of the variables that control the cash flow of the project.

3. Methodology

For the development of this project the following working methodology is defined:

1. Bibliographic review on the generation of agricultural waste in the Province of Almeria will be carried out and presented.

1. An overview of the prevailing regulatory framework on generating renewable energy in Spain and its downhill current policies that would impair the implementation of the project will be explained. For this, the available literature, project reports, companies and biogas project consultants will be approached.

2. The biogas production process and the principles of operation of a biogas plant will be studied. The different available technologies will be also studied in order to clarify the alternatives for the production of biogas and which are the most suitable for the particular case of the project, but they will not be included in the memory to reduce its extension. For all this, the available literature, project reports, companies and biogas project consultants will be approached.

3. From substrate specifications that currently owns the laboratory plus the results obtained from the biogas efficiency tests on samples of GVW, the energy potential of the substrates will be studied.

4. Based on the available volume of GVW estimated in the region and its energy potential the installable power capacity in the area will be estimated.

5. In view of the information gathered regarding biogas production and considering the relation of benefit between the greenhouses/farmers and the biogas plant, a general model will be recommended and the process to biogas obtaining and the biogas plant installation will be described.

6. Consulting with suppliers, using information from similar projects of biogas production and according to previously settled specifications, the investment and the operational costs for the biogas plant implemented will be determined as well as the possible income from the commercialization of its energy, fertilizer and CO_2 generation. Thus aiming to economically evaluate the project and to deliver relevant indicators. The method of calculation will be explained.

7. A sensitivity analysis will be carried out in order to understand the variables that would positively or negatively affect the project. As for example the sale price of the energy, the efficiency of the substrate, variable costs of production, etc. The method of calculation will be explained.

8. Based on the technical and economic analysis carried out, it will be concluded with respect to the project and definition of lines of work following the present study will be presented.

4. Greenhouse vegetable waste generation in Almeria

The agriculture in the Province of Almeria has experienced a huge development in the last three decades. The economic engine of this movement forward has been the primary sector and specially the intensive agricultural sector under plastic. This horticultural sector is developed by a huge amount of greenhouses that have been increasing throughout the last twenty years. In 1984 the area was of 11.000 ha and nowadays in 2016 it is around 29.000 ha. For that reason upon the settlement of this broad amount of greenhouses, the Almeria region is today placed as the biggest vegetable producer of Spain as well as one of the leaders worldwide.

Therefore, as it is logical, the production of this huge amount of vegetables entails the apparition of a stunning amount of waste mainly of organic composition accounting to 2.013.210 tons annually (López et al., 2016). Despite of Almeria currently has a 1,7 MW greenhouse gasification plant, being the only one in Spain with these characteristics (AAE, 2015), most of the GVW are currently subjected mainly to a composting process which allows to obtain organic fertilizers. However, the annual generation of GVW is far superior to the capacity of treatment of the composting plants thus accumulating and generating an important environmental impact in the area. As a matter of fact, the abandonment of waste in bays and lots is sanctioned since it can have many negative consequences. Among these, the vegetable wastes can be the focus of the spread of diseases and pests, which can seriously affect adjacent crops; it can degenerate in rotting with the resulting bad smell and contamination of the aquifers; as well as having a negative visual impact (Parra, 2004).

During its development aforementioned, a “plastic sea” parallel to the sea has been spread throughout the West, which clearly clarifies its leadership in exportations of these products today (Figure 1).

Figure 1.- The ‘’plastic sea’’ in the Almeria Province**.** Source: Google Earth.

The main crops are tomato, pepper, cucumber and zucchini, as it is identified graphically in the Figure 2, hogging the first three around 60% of the production.

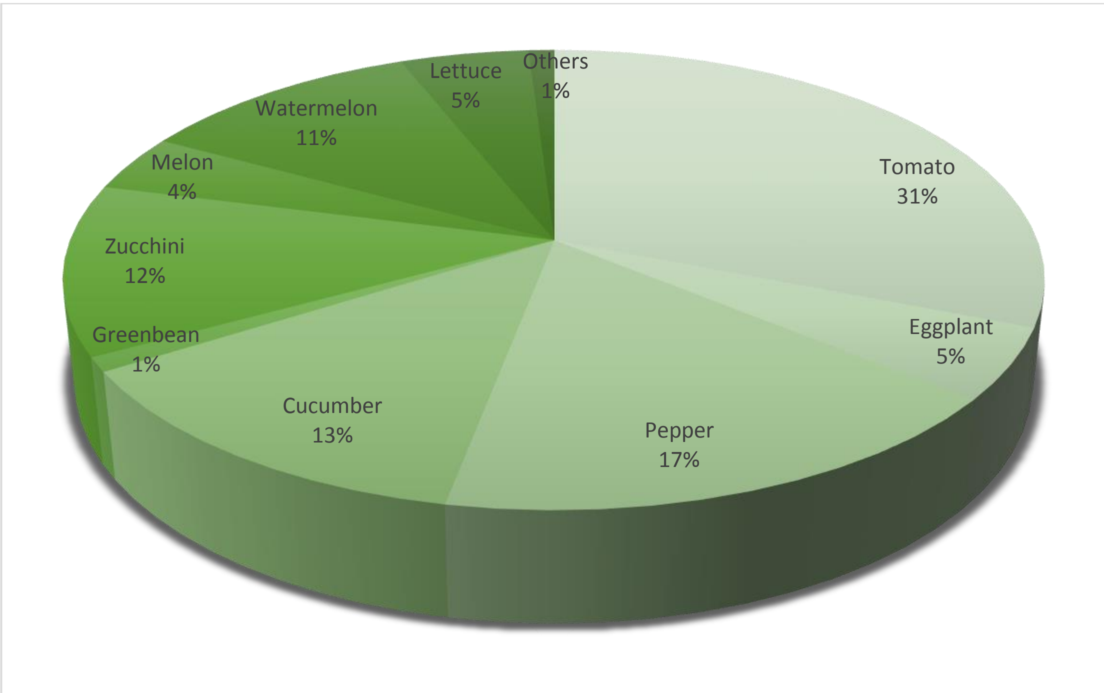


Figure 2.- Production by types of fruit and vegetable products of the province of Almeria during the 2012-2013 season. Source: Own elaboration according to Cabrera et al. (2015).

In addition, the management and treatment of GVW is complex due to its heterogeneity, - including polyethylene wires used as tutors –its high dispersion that makes expensive and difficult the transport and storage operations and finally its generation throughout the year. During the months of May and June, at the end of the spring crops, and in the month of February, at the end of autumn and winter, about 70% of the remains are generated. As aforementioned, the extended current treatment in this region is the composting which allows to obtain a rich product with fertilizing and stabilizing feature. In the Table 1 are listed the current installations in the region and its poor annually capacity of treatment accounting approximately to one tenth of the total GVW generation.

Table 1.- Current treatments of the vegetable residues en the Province of Almeria (Consejería de agricultura, pesca y desarrollo rural, 2016).

Name of the instalation	Province	Municipality	Treatment	Capacity (t/year)
Reciclados Almerienses 2005, S.L.	Almeria	Almeria	Vermicompost	7.920
Ejido Medio Ambiente, S.A.	Almeria	El Ejido	Composting	150
Albaida Residuos, S.L. (Paraje Cueva del Algarrobo)	Almeria	La Mojonera	Composting	135.000
Transportes y Contenedores Antonio Morales, S.A. - El Jabonero	Almeria	Níjar	Composting	-
Ecotech Valoriza, S.L.	Almeria	Rioja	Vermicompost	1.800
Servicios Ambientales Las Chozas, S.L	Almeria	El Ejido	Composting	47.600

5. Prevailing regulatory framework on REG in Spain

In the adoption of the Electric Power Act in 1997, Spain has had a special tariff regime with strong financial incentives to renewable energy and combined heat and power (CHP) producers (International Energy Agency [IEA], 2009). In 2004, the Royal Decree 4361/2004 introduced an important change to this system, allowing the electricity generators under the special regime to choose between either getting a regulated tariff selling the electricity to the grid operator or a market price plus a premium selling the electricity on the wholesale market which will vary according to the hourly wholesale (pool) price. This costs were supposed to be covered by a third-party access tariff, paid by consumers. At any rate, both options still entailed a bounty from its power production which remained their facilities cost-effective while respectful with the environment.

The table below represents the average data of subsidies that the energy producers from renewable energies received:

Table 2.- Feed-in Tariffs and Premiums for Electricity from Renewable Sources in Spain, 2008 (IEA, 2009).

	Fixed price	*Market option*		
	Average tariff received (cent€/kWh)	Average prenium (cent€/kWh)	Average market price paid to the technology (cent€/kWh)	Total average remuneration (cent€/kWh)
Solar PV	32.00			
Solar Thermoelectric	27.84	26.45	6.83	33.28
Wind	6.88	2.41	6.16	8.57
Hydroelectric	8.00	2.20	6.42	8.62
Biomass	10.52	4.84	6.53	11.37

Notes:
1. The table shows the average remuneration per technology but the Spanish feed-In tariff system has 16 categories (sometimes with sub-categories). The real remuneration for each category/sub-category may be different from the average.

On 2013, the Royal Decree Law 2/2013 containing urgent measures in the electricity and financial sectors was enacted for renewable energy, cogeneration and residues facilities. First of all the funding case consisting of the combined system of pool price plus a premium was immediately removed. As a consequence, only the fixed FiT system remained, considering that if renewable operators choose the combined system, they will receive only the pool price as companies generating from non-renewable sources. Besides, once the remuneration option was chosen, it was no longer possible to change from one system to another in order to prevent producers from adopting the mechanism whereby they sold electricity to the market when the market price was higher than the FiT and went back to the FiT when the market price went down. According to the government, this fluctuation contributed to an increase on energy prices. Besides, the wholesale Spanish electricity market is very volatile and unpredictable. The Figure 3 shows its evolution of prices in the last 6 years.

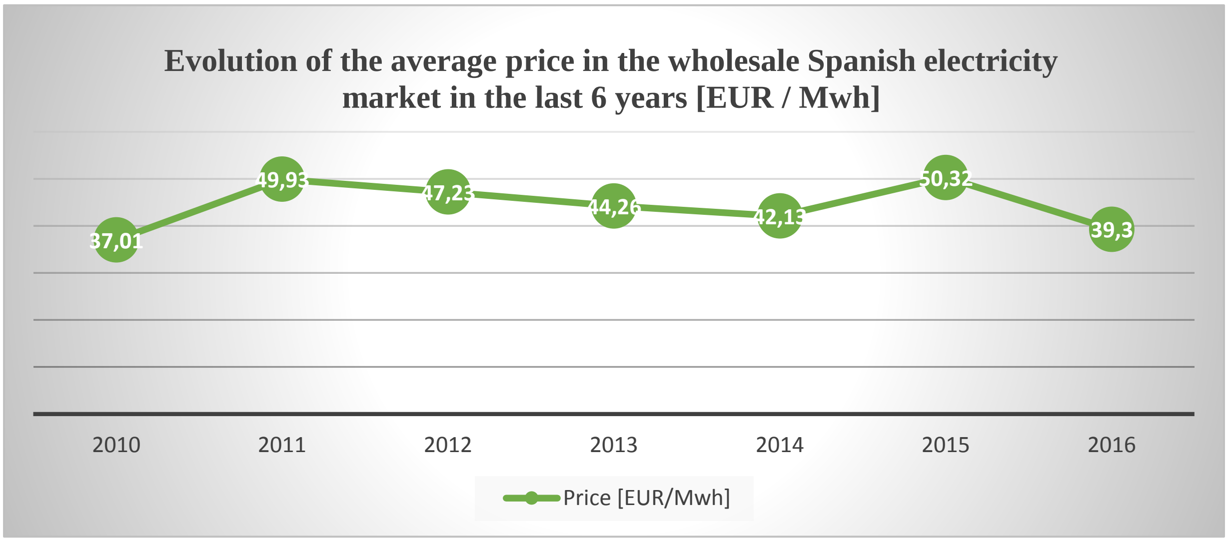


Figure 3.- Graphic of the evolution of the average price in the wholesale Spanish electricity market. Source: Own elaboration according to Monforte (2016).

For example, according to calculations from the data of the Table 2, while the average price in the wholesale Spanish electricity market in 2016 with the current system for any kind of generator was 50,32 EUR/MWh as we can see in the Figure 3, with the granting of premiums in the past system an energy generator from biomass and wind would deposit 113,7 EUR/MWh and 85,7 EUR/MWh respectively making a renewable exploitation much more profitable.

The incoming movement executed by the government was more concerning for the renewable energy producers since it entailed the complete disappearance of any kind of subsidies granting. Now is very hard to obtain subsidies and they are practically inexistent. In the Annex A you will find some information about the remuneration that a biogas plant can sadly obtain currently.

Nonetheless, the Energy Reform was needed urgently since the Spanish government had and currently still has an issue to solve. The unpleasant scenario presented is because of the disastrous management of the Spanish energy market so the government accumulated a tariff deficit of € 30 billion which is, at the moment, financed through a debt held by the Spanish five largest energy companies and, accordingly, not reflected in the actual electricity tariffs (Deloitte, 2015). To prevent the tariff deficit from growing, increasing the access tariffs to the final customers, reducing remuneration paid to network operators and cutting incentives were measurements implemented.

And why did the tariff deficit increased so fast and never stopped? Because while the price of centime/ KWh in Spain remained constant since it was considered as an essential product for the population according to the Spanish government, both the raw materials and the expenses to produce such energy never stopped increasing. Because of that and alongside the rapid expansion of renewable energies, the energy Spanish became utterly unstable and unsustainable.

To turn the situation even worse, in 2015 the Royal Decree 900/2015 was approved, establishing charges on existing and new self-consumption RES plants, both on capacity and generation levels. According to RD 900 these are not taxes or compensation for utility losses, but contributions to overall system costs.

The Spanish Energy Reform is contrary to the general interests of Spain and Europe. It penalizes, retroactively, those who invested in the development of renewable energy while benefiting dirty technologies. It prevents self-consumption, imposing additional tolls that make it unfeasible to produce energy in buildings, which benefits large suppliers. Finally, we can take for granted that it blocks future investments in renewable energies in Spain from both, native or foreign energy companies.

Finally, it can be observed that nowadays at the national level there is no further development in biogas production projects, unlike countries like Germany that have more than five thousand plants in operations with an installed capacity of 3000 MW (Wilken, nd) and laws that encourage the development of all renewable energies.

On the other hand, there is something positive since in Spain renewable energy plants are statutorily entitled to priority access to, connection to and use of the grid and these are granted priority dispatch in the electricity markets at no cost. All the same the follow-up and recommendations of the Community Institutions are helping to solve the problem of the tariff deficit in Spain, although at the cost of a drastic reduction of income in all the activities of the chain of supply.

Besides, according to (Deloitte, 2015) in 2012 the share of renewables in Spain’s final energy consumption amounted to 14,3% and the target set by the European Commission for 2020 is 20% - with a more ambitious target of 20,8% set at the national level - (Deloitte, 2015).

In conclusion, it is obvious that the despite of the adversities oncoming investments are necessary. Nonetheless, assuming a future scenario that reinstates the incentives granting again in a new stable Spanish energy market is rather a utopia. For this reason, today uncertainty remains high but there are still options for the development of renewable energies. For example, producers should stop relying on unpredictable government decrees in the development of their business models and they can develop projects with off-take agreements signed with consumers willing to consume renewable power for sustainability reasons. The ethics, the moral and the new more effective technologies will allow to achieve the oncoming goals as well as those of the Spanish energy market.

6. Anaerobic digestion

6.1 Definition

Anaerobic digestion is a microbiological and biochemical process very complex both by the number of biochemical reactions that take place, such as for the amount of group of bacteria involved in them. In fact, many of these reactions occur simultaneously.

It is a renewable and clean energy process with reduction of greenhouse gas emissions, reduces fossil fuel consumption, reduces methane emission avoiding the deterioration of the ozone layer and reduces the degradable organic matter maintaining the nutrient concentrations, which allows to have the same richness of nutrients obtaining a digested used as a biofertilizer.

Cycle of anaerobic biochemical reactions occurring in fermentation chambers is composed of four stages and the bacteria responsible for this process are strict anaerobes:

- Hydrolysis − polymers: hydrocarbons, fats and proteins are decomposed to monomers: sugars, glycerin, amino acids, and fatty acids; by the acidic or fermentative microorganisms.
- Acidogenesis − monomers are converted to short-chain fatty acids, alcohols, hydrogen, carbon dioxide and methane and other intermediates by the acidogenic bacteria.
- Acetogenesis − fatty acids are converted to acetic acid, hydrogen and carbon dioxide by the acetogenic bacteria.
- Methanogenesis − from acetic acid and hydrogen arises a mixture of methane and carbon dioxide, the final product, by two types of microorganisms. Those that degrade acetic acid to methane and carbon dioxide (methanogenic acetoclastic bacteria) and those that reduce carbon dioxide with hydrogen to methane and water (hydrogenophilic methanogenic bacteria).

In the Figure 4 in the following page the different phases of the anaerobic digestion process are shown schematically as well as the intermediate products generated:

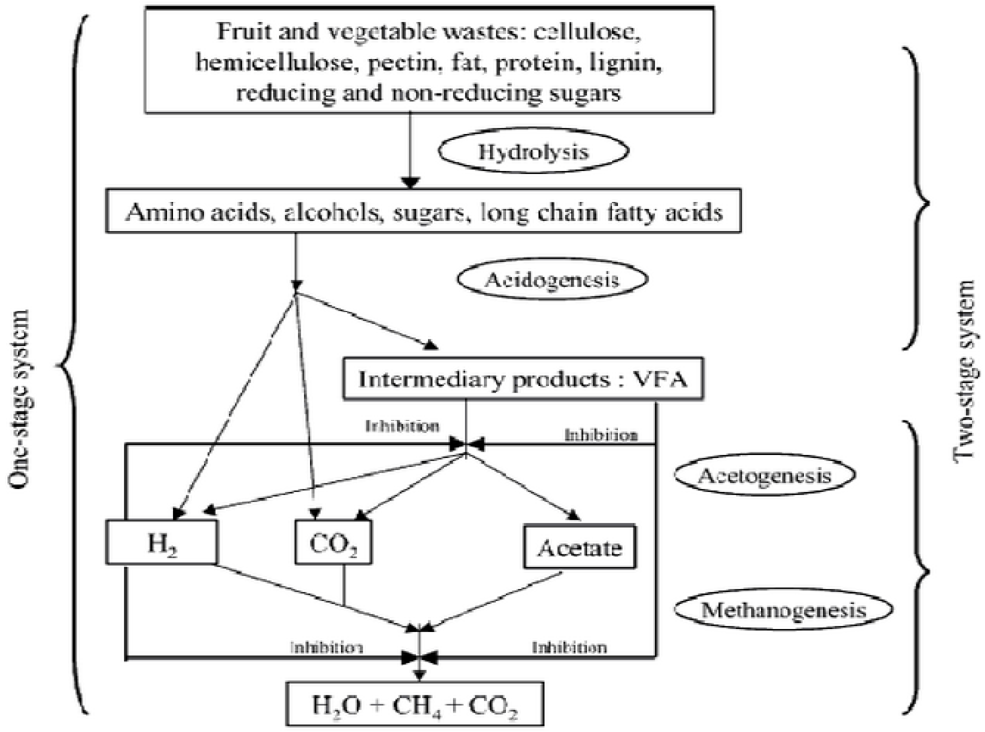


Figure 4.- Diagram of reactions of anaerobic digestion of fruits and vegetable wastes. Source: (Ramesh et al., 2018)

As it is observed, methane is not the only gas produced in the degradation of organic matter under anaerobic conditions, it is a gas mixture known as biogas. It is composed of 60% methane (CH_4), approximately 38% carbon dioxide (CO_2) and traces of other gases. Nonetheless, the composition or richness of the biogas depends on the digested substrate and the operation of the process and that is why the concentrations can vary substantially as we can see in the Table 3.

Table 3.- Chemical composition of biogas (Cepero et al., 2012)

Component of biogas	Concentration [%]
CH4	40 – 70
CO2	30 – 60
H2S	0,1
H2	0,1
CO	0,1
N2	0,5
O2	0,1

Biogas can be used in any type of commercial equipment for the use of natural gas, for example in applications such as: cogeneration, burners, stoves, infrared, lighting, motors, electricity generation, heat and mechanical power.

Another final product, apart from biogas, is the so-called digested product, which is the mixture of the already digested sludge and the microbial biomass produced. During the anaerobic process, part of the organic matter is transformed into biogas, so that the organic matter content is lower than that of the influent. It is also a more mineralized and stabilized product than the influent, which normally increases the content of ammonia nitrogen and decreases the organic nitrogen.

6.2 Influence of the environmental and operational parameters

In order to develop the anaerobic digestion process, adequate environmental and operational conditions must be maintained, for which various parameters are controlled. Among the most important are the following: temperature, pH, particle size, nutrients, solids content, residence time, presence of compounds that inhibit the process and agitation.

a) Temperature

As the temperature increases, the growth rate of the microorganisms increases and the digestion process is accelerated, leading to greater biogas productions. The operating temperature in the digester is considered one of the main design parameters due to that in case of abrupt temperature variations in it the process can destabilize.

There are two main ranges, the mesophilic range (between 25ºC and 45ºC) and thermophilic (between 45 ºC and 65ºC). The mesophilic range is the most used, although the thermophilic is increasingly being used to achieve a greater speed of the process and a better elimination of pathogenic organisms. However, the thermophilic range is usually more unstable than any change in the conditions of operation and also presents greater problems of inhibition of the process due to sensitivity to some compounds, such as ammonia.

b) pH

It is one of the most common control parameters because in each phase of the process the microorganisms have maximum activity in a different pH range. Thus, the optimum pH range of the microorganisms must be kept close to neutrality, and may fluctuate between 6.5 and 7.5. Its value in the digester not only determines the biogas production but also its composition.

c) Alkalinity

Alkalinity is a measure of the buffer capacity of the medium. It can be provided by a wide range of substances, being therefore a nonspecific measure. In the pH range of 6 to 8, the main chemical balance that controls alkalinity is carbon dioxide-bicarbonate. To ensure buffer capacity and avoid acidification, alkalinity higher than 1,5 g / l $CaCO_3$ is recommended.

The ratio of alkalinity is defined as the ratio between the alkalinity due to volatile fatty acids (VFA) and that due to bicarbonate (alkalinity). It is recommended not to exceed a value of 0,3-0,4 to avoid acidification of the reactor.

d) Particle size

During the anaerobic digestion of a solid residue, the rate of solubilization of the organic matter will be closely related to the granulometry of the residue (Sharma, 1988). Thanks to a previous pretreatment such as a brief crushing or an intense hydrolysis a particle size can be achieved allowing an increase of the available surface. Hence, allowing to improve the biological process and the yield of biogas production on substrates with a high fiber content and low biodegradability such as plant residues.

e) Redox potential

The recommended values must be less than -350 Mv.

f) The nutrient content

One of the inherent advantages of the anaerobic digestion process is its low need for nutrients as a consequence of its small growth rate. However, carbon and nitrogen are the main sources of food for methane-forming bacteria and they are of big importance for the fermentative process so a Carbon / Nitrogen (C/N) ratio of 20-30 is recommended as the optimum. The process requires, in addition to a source of carbon and energy, the presence of several mineral nutrients such as nitrogen, sulfur, phosphorus, potassium, calcium, magnesium, etc.

g) The presence of toxins and inhibitors

Inhibitory substances are compounds that are either present in the waste before digestion or are formed during the anaerobic fermentation process. These substances reduce the performance of digestion and may even cause the complete destabilization of the process.

There are a lot of substances that can inhibit anaerobic digestion. Among them, oxygen should be noted, although its inhibitory effect is not permanent, since in the bacterial flora there are microorganisms that will consume the oxygen that the medium may have. Also, if the biomass is rich in nitrogen, an excess of ammonia can be produced then inhibiting the process.

Other inhibitors are heavy metals, which act on methanogenic microorganisms. In addition, some organic substances, such as antibiotics and detergents in certain concentrations, can inhibit the process. Finally, a high concentration of volatile acids can produce an inhibitory effect.

Table 4 shows the inhibitory concentration values of the most common inhibitors. These values are indicative, since bacteria can adapt over time to the most unfavorable conditions.

Table 4.- Inhibitory concentration values of the most common inhibitors (Jarauta, 2005)

Inhibitors	Concentration [mg/ml]
Sulfide (Sulfur)	200
Copper (Cu)	10 – 250
Chrome (Cr)	200 – 2000
Zinc (Zn)	350 – 1000
Nickel (Ni)	100 – 1000
CN	2
Sodium (Na)	8000
Calcium (Ca)	8000
Magnesium (Mg)	3000

h) Agitation

There are different reasons to maintain an adequate degree of agitation in the digestion medium such as to maintain the mixing and the homogenization of the substrate, to uniform distribution of heat to maintain the homogeneous temperature, to favor the transfer of gases or to avoid the formation of foams and sedimentation. Agitation may be mechanical or pneumatic through the bubbling of recirculated biogas at the appropriate pressure. In any case should be violent, because it could destroy the aggregates of bacteria.

Depending on the type of reactor, the level of energy necessary to favor the transfer of substrate to each population or aggregates of bacteria must be transferred to the system, as well as homogenized to maintain low mean concentrations of inhibitors.

i) Hydraulic retention time (HRT)

It is the quotient between the volume and the treatment flow, ergo, the mean residence time of the influent in the reactor, subject to the action of the microorganisms to reach the energy levels and / or reduction of the pollutant load that have been prefixed. It is expressed as follows:

$$HRT = \frac{m^3\ digester}{m^3 substrate/day}$$

Figure 5 shows the general trend of organic matter removal rates (expressed in the form of volatile solids, SV) and of specific gas production, per unit of reactor volume, as a function of retention time.

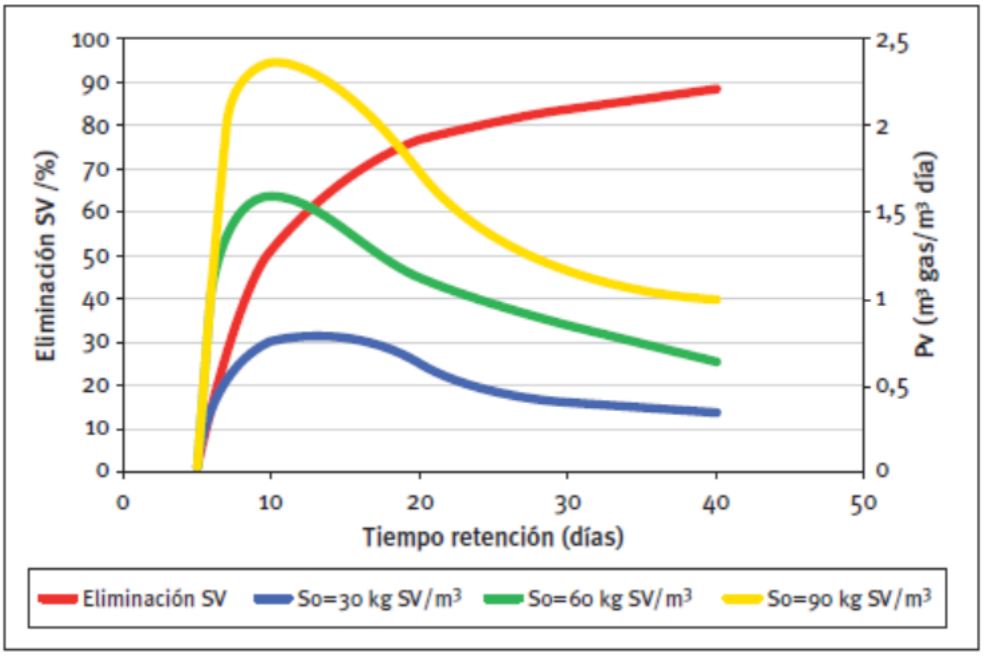


Figure 5.- Volatile solids removal, VS (%) and volumetric production of Pv gas (m^3biogas / m^3 dig · day) for a continuous anaerobic reactor of complete mixing, depending on the hydraulic retention time (IDAE, 2007).

This parameter is closely linked to the type of substrate and its temperature. The selection of a higher temperature will imply a decrease in the required retention times and, consequently, the reactor volumes necessary to digest a certain volume of material will be lower.

j) Organic loading rate (OLR)

This parameter is the amount of organic matter introduced per unit of volume and time. Low values imply low concentration in the influent and / or high retention time. The increase in the OLR implies a reduction in gas production per unit of organic matter introduced (see Figure 6), having to find an optimal technical / economic value for each installation and waste to be treated. Besides, if it is too low, the metabolic activity of the bacteria is lower and only small amounts of gas will occur. If the feed rate is too high, there will be an overload that will increase the formation of volatile acids with the consequent increase of the proportion of carbon dioxide in the gas or what would be even worse, the stoppage in the production of biogas due to inhibitions of bacteria involved in fermentation due to high concentrations of fatty acids and variations in pH. It is expressed as follows:

$$OLR = \frac{kg\ VS}{m^3 digester \cdot day}$$

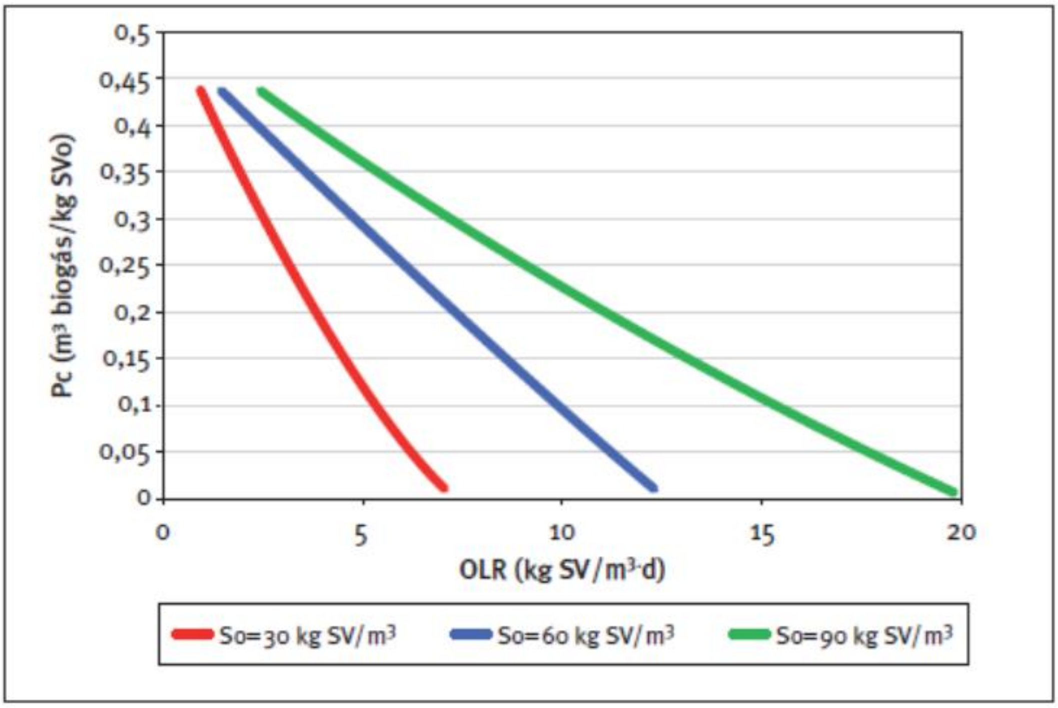


Figure 6.- Gas production per load unit based on the organic loading rate (OLR) (IDAE, 2007).

7. Experiment design

The experiments of energy valorization of GVW allow us to verify the existing big potential in the Region of Almeria on generating both electric and thermal energy based on biogas. These experiments were carried out in the Eco-technology laboratory at Poznan University of Life Sciences which is the largest biogas laboratory in Poland. This laboratory has over 250 fermenters working in temporary or permanent mode (Cieślik et al., 2016).

The physical – chemical analysis of the vegetable wastes which fed the reactors are essential to conduct in order to establish a proper characterization of the substrates. The C/N ratio test allows to select the proper proportions for a fermentation process in a biogas plant but given the lack of equipment during the experimental period this test was not performed. Conductivity would be also important in the digestion process since it is a tool that tells us about the correctness of the process flow in terms of conversion of organic matter to the mineral form. On the other hand, the mesophilic fermentative inoculum used to conduct the biogas production efficiency testes and the simple continuous fermentation test was gained by separating the liquid fraction of the digestate pulp from an operating agricultural biogas plant in Poland.

7.1 Physical – chemical analysis test stand

The following physicochemical parameters were examined in the selected discarded fruits: melon, eggplant, zucchini, cucumber and pepper according to Polish standards - Total Solids or dry matter content (PN-75 C-04616/01), Volatile Total Solids or dry organic matter and ashes content (PN-Z-15011- 3) and pH (PN-90 C-04540/01) -. These parameters were essential for the calculation of the biogas efficiency of the substrates into the units m3/Mg FM.; m3/Mg TS; m3/Mg VTS (Lewicki et al., 2016).

Analysis of substrates and characterization of the fermentation process was based on the labels parameters made according to the following methodology:

- **pH:** the solid was measured in aqueous solution immersing electrodes and thermometer in test sample (internal standard PE 001/2012 and PE 002/2012) using the multifunction CPC-411 Business Elmetron;
- **dry mass**: drying at 105 ° C for 24 hours in a desiccator (PE 003/2012);

- **dry organic mass**: the burning of dried attempts at 550 ° C by 3-5 hours in the muffle furnace (PE 004/2012);

7.2 Biogas efficiency test stand

The experiments of biogas production efficiency were conducted through anaerobic digestion in the selected discarded fruits: melon, eggplant, zucchini, cucumber and pepper in a set of multi-chamber biofermentor (Figure 7) constructed in the Laboratory of Eco-technologies. This biofermentor is commonly used for testing biogas efficiency for large amount of biomass samples. Methane fermentation was conducted in the glass gastight and thermostatted reactors with capacity of 2 dm^3. The tested substrates were placed in the reactors (170 g) and then flooded with sufficient amount of inoculum (1030 g) according to the standards. The reactors were placed in a water bath with temperature of 39 ° C ± 1 (mesophilic fermentation) to ensure optimal conditions for the methane fermentation process. Biogas produced in each separate chamber was transferred to cylindrical store filled in with liquid resistant for gas solubility.

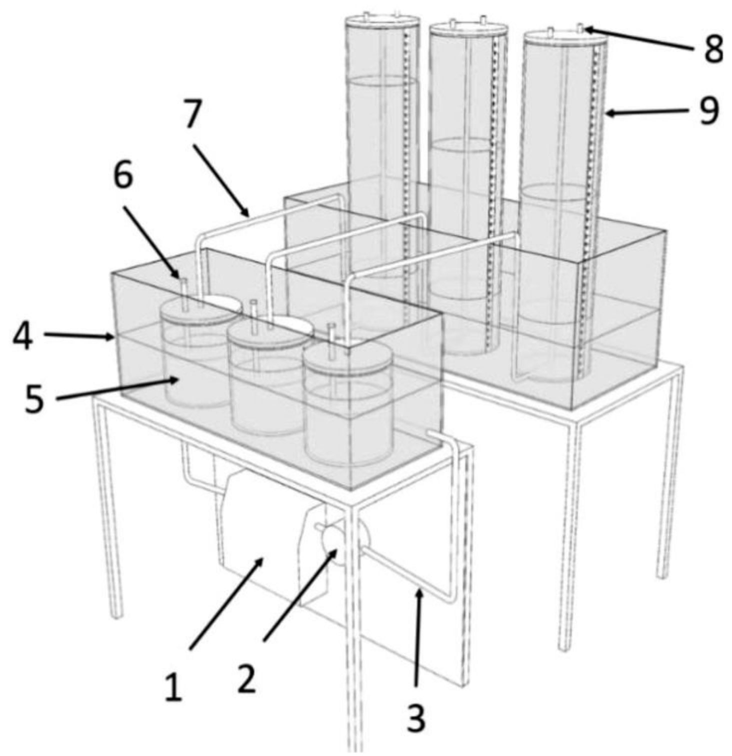


Figure 7.- Scheme of biofermentor for biogas production research (3-chamber section) 1 - water heater with temperature regulator, 2 - water pump, 3 - insulated conductors of calefaction liquid, 4 - water coat, 5 – fermentation reactor with charge capacity 2 dm3, 6 - sampling tubes, 7 - biogas transporting tube, 8 - gas sampling valve, 9 - biogas volume-scale (Cieślik et al., 2016).

The samples were tested in 3 replications and the readings of produced biogas volume were made with 24-hour intervals. The test gases were methane, carbon dioxide, ammonia, hydrogen sulfide and oxygen in test, and the results were recorded to the nearest 0,01 dm3. Measurements were made using a certified GA5000 gas analyzer of GeoTech Company (PE 008/2013). Ranges detected by the gas analyzer were as follows: 0÷100 % CH_4, 0÷100 % CO_2, 0÷25 % O_2, 0÷10.000 ppm H_2S and 0÷1.000 ppm NH_3. Production of biogas, including methane was calculated using mathematical formulas created in an Excel spreadsheet which allows to take into account the inoculum activity as well as to calculate the means of the 3 replications easily. The analyzer was calibrated once a week using the standards: 65 % CH_4, 35 % CO_2,, 500 ppm H_2S and 100 ppm NH_3.

The following tasks has been carried manually during the period of the test for the three replicas conducted:

a) Daily check of the biogas volume production.
b) Check of the biogas quality (when the volume is equal or superior to 0,45 ml).
c) Daily manual mixing of the medium.

7.3 Simple continuous fermentation test stand

Since the impossibility to obtaining real samples from the Greenhouses of Almeria a simple continuous fermentation test has been conducted with a mixture of vegetable wastes from a countryside farm in Poland. This substrate allows to represent fairly accurate the experimental conditions required.

In regards to the laboratory equipment, the test basically consists on the same reactor used for biogas efficiency tests (Figure 7) but with a feed and outlet system which are controlled manually while also allow to regulate the pH value if is necessary (Figure 8).

The samples were tested in 3 replications and the readings of produced biogas volume were made with 24-hour intervals. The test gases were methane, carbon dioxide, ammonia, hydrogen sulfide and oxygen in test, and the results were recorded to the nearest 0,01 dm3. Measurements were made using a certified GA5000 gas analyzer of GeoTech Company (PE 008/2013). Ranges detected by the gas analyzer were as follows: 0÷100 % CH_4, 0÷100 % CO_2, 0÷25 % O_2, 0÷10.000 ppm H_2S and 0÷1.000 ppm NH_3. Production of biogas, including methane was calculated using mathematical formulas created in an Excel spreadsheet which allows to take into account the inoculum activity as well as to calculate the means of the 3 replications easily. The analyzer was calibrated once a week using the standards: 65 % CH_4, 35 % CO_2,, 500 ppm H_2S and 100 ppm NH_3.

Proper preparation of the samples has a significant impact on the speed of the process of biological waste treatment as well as on the composition of the biogas, thus the original samples which were too dry were moisten being diluted the following way:

From an initial sample = 500 g; from 15.1% of initial dry content to 10% of final dry content:

$$\frac{500}{15{,}1} * 10 = 331{,}1\ g\ of\ Sample\ (15{,}1\%\ dc)$$

$$\frac{500}{15{,}1} * 5{,}1 = 168{,}5\ g\ of\ water\ to\ add\ or\ 500 - 331{,}1\ g = 168{,}5\ g\ of\ water\ to\ add$$

The batch bioreactor technology available to conduct the test presented some deficiencies in comparison to the big and monitored by software lab scale bioreactors. 1 Kg of inoculum was added to each reactor starting with 0,5 [g · day^{-1} · Kg^{-1}] of organic load. This fermentation substrate was added by means of pumping through pipes rather than introducing the real particle sizes. For this reason the substrate has been previously diluted and crushed to be able to fit through the syringe and feeding tube. At any rate, before being loaded to the reactors, VW must undergo the previous hydrolysis process which has not been conducted in this experiment so that this previous crushing process replaces it.

Finally, unlike to what the VDI 4630 protocol states, the fermentation process lasted 7 efficient weeks instead of 18 since the samples got contaminated inhibiting the process. A continuous fermentation test is an experiment that must be carried with accuracy maintaining the proper parameters to prevent inhibitions. All the same, it is sharply important to increase the organic load throughout the process to reach a stable biogas production on its maximum efficiency. In case the process follows the regular protocol the organic load should be increased every 14 days. However, in this case the lack of time was the limiting factor and the speed of feeding had to be much faster. However, under no circumstances the processes in the digesters were inhibited by overloading and increasing the concentration of organic fatty acids and thus wasting the experiment. It is assumed since the FOS/TAC test was established in order to monitor the amount of organic fatty acids in the medium, and thus controlling the feeding doses and allowing to stop the feeding properly.

The following tasks has been carried manually during the period of the test for the three replicas conducted:

d) Daily check of the biogas volume production.
e) Check of the biogas quality (when the volume is equal or superior to 0,45 ml).
f) Daily manual mixing of the medium.
g) Daily pH checking of the medium.
h) Daily removal of the output from the medium (the amount relies in the daily fed).
i) Daily introduction of the feeding to the medium.
j) FOS/TAC test every 3 days.

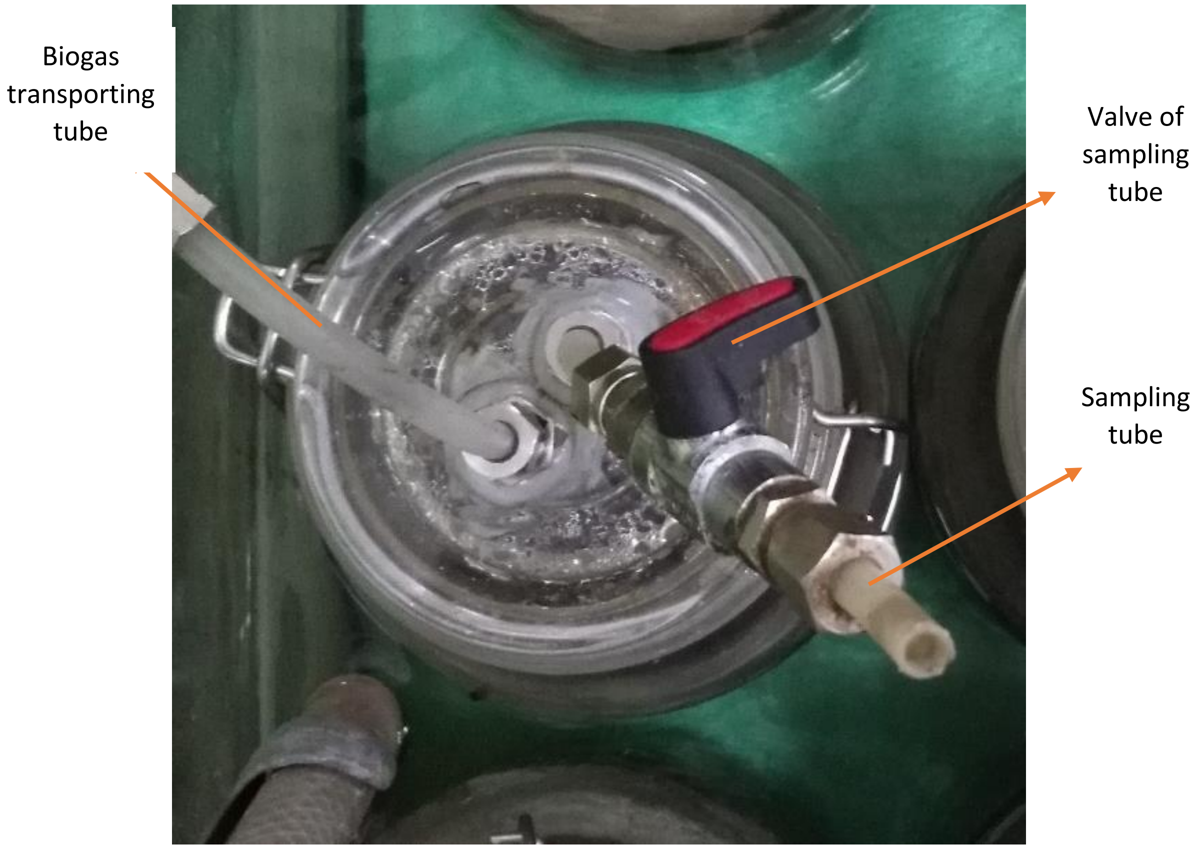


Figure 8.- Picture of fermentation reactor. Source: Taken by myself.

7.4 Results and discussion

As aforementiened in the previous section, the substrates were initialy tested to know the parameters of humidity and dry matter content [% d.m.], organic dry matter content [% d.o.m.] and pH. The table 5 shows the results of the characterizations conducted in this project alongside some others conducted in the past in the lab by other researchers which are marked with an asterisk.

Table 5.- Substrates characterization. Source: Own elaboration from experimental data and lab resources.

Substrate	Humidity [%]	[% d.m]	[% d.o.m.]	pH
Tomato fresh leaves*	89,85	10,15	73,34	6
Tomato stalks*	65,39	34,61	81,67	5,8
Tomato discarded fruits*	95,21	4,79	90,02	4,4
Pepper discarded fruits	94,58	5,42	90,98	5,5
Eggplant discarded fruits	93,19	6,81	91,32	-
Cucumber leaves*	89,92	10,08	77,75	7,2
Cucumber discarded fruits	95,49	4,51	87,72	6,4
Greenbean peel*	89,25	10,75	39,14	-
Greenbean discarded fruits*	88,23	11,77	93,97	5,5
Zucchini discarded fruits	95,64	4,36	84,36	6
Melon discarded fruits	95,29	4,71	87,84	6
Watermelon discarded fruits*	93,86	6,14	84,12	-

In the Table 6 one can observe the biogas and methane efficiencies as well as their methane content in fresh matter. On the other hand, to better compare the energy potential of the analyzed organic wastes, the tested substrates have been summarized in terms of efficiency for the content of dry weight and the organic dry weight, as shown in Table 7.

Table 6.- Biogas and methane accumulated in fresh matter. Source: Own elaboration from experimental data and lab resources.

		Fresh matter	Fresh matter
Substrate	**Methane content [%]**	**Methane accumulated [m3/Mg f.m.]**	**Biogas accumulated [m3/Mg f.m.]**
Tomato fresh leaves	43,77	14,61	33,39
Tomato salks	41,61	12,98	31,19
Tomato discarded fruits	51,77	16,78	32,41
Pepper discarded fruits	53,13	18,97	35,71
Eggplant discarded fruits	50,02	19,96	39,91
Cucumber leaves	49,37	17,38	35,21
Cucumber discarded fruits	53,53	14,94	27,91
Greenbean peel	43,80	13,61	28,39
Greenbean discarded fruits	46,89	28,03	59,79
Zucchini discarded fruits	44,14	11,51	26,07
Melon discarded fruits	46,46	15,69	33,79
Watermelon discarded fruits	43,05	14,28	33,18

The methane produced by tone of dry matter (DM) and organic dry matter (ODM) can be calculated by the following formula and resulting to the Table 7.

$$\frac{\boldsymbol{m^3CH_4}}{\boldsymbol{T\ ODM}} = \frac{m^3CH_4}{x\ T\ FM} \cdot \frac{100t}{y\ T\ DM} \cdot \frac{100t}{z\ T\ ODM}$$

Table 7.- Biogas and methane accumulated in dry matter and organic dry matter. Source: Own elaboration from experimental data and lab resources.

	Dry matter	Dry matter	Organic dry matter	Organic dry matter
Substrate	**Methane accumulated [m3/Mg d.m.]**	**Biogas accumulated [m3/Mg d.m.]**	**Methane accumulated [m3/Mg o.d.m.]**	**Biogas accumulated [m3/Mg o.d.m.]**
Tomato fresh leaves	144,03	329,04	**196,39**	448,70
Tomato stalks	283,97	682,42	**317,65**	763,35
Tomato discarded fruits	350,25	676,58	**389,08**	751,59
Pepper discarded fruits	350,07	657,17	**384,77**	724,24
Eggplant discarded fruits	293,16	586,09	**321,03**	641,80
Cucumber leaves	172,43	349,22	**221,78**	449,19
Cucumber discarded fruits	331,30	618,88	**377,68**	705,52
Greenbean peel	126,61	264,04	**323,50**	675,06
Greenbean discarded fruits	238,15	507,99	**253,43**	540,58
Zucchini discarded fruits	263,99	597,94	**312,93**	708,79
Melon discarded fruits	333,12	717,41	**379,24**	816,72
Watermelon discarded fruits	232,66	540,50	**276,59**	642,55

Finally, the Table 8 shows the standard deviation over the three replications conducted in each sample of the batch assays.

Table 8.- Substrates characterization. Source: Own elaboration from experimental data and lab resources

Substrate	[% d.m]	[% d.o.m.]	Biogas efficiency [m3/Mg f.m.]
Zucchini discarded fruits	0,186	1,885	1,240
Cucumber discarded fruits	0,192	1,628	1,325
Melon discarded fruits	0,285	1,421	1,716
Pepper discarded fruits	0,210	1,845	1,569
Eggplant discarded fruits	0,143	1,292	1,362

Definitely, from a first look of the results it seems to be that the methane potential of the substrates is extremely low although it is due to there is a lot of humidity on them. Nonetheless, in order to confirm that the results of the tests are reliable and coherent their methane accumulated in ODM have been compared with other batch assays conducted on vegetable samples. Hence, according to Wang (2010), the methane potential of some of them are the following:

Table 9.- Methane accumulated in organic dry matter of some vegetable substrates (Wang, 2010).

Substrate	Sugarbeet leaves	Grass	Corn stalker	Willow	Marrow kale
Methane accumulated [m3/Mg o.d.m.]	290	290 - 310	290 - 390	120 ± 10	310 ± 20

After this comparison we can confirm that the results are reliable and they are around typical values and that we can continue with the evaluation.

By analyzing the compiled data, the tomato discarded fruits have proven to be the best substrate for biogas accumulated production basing on the calculations of the organic dry weight. This would be a good thing since the tomato is the dominant crop in the greenhouses of Almeria.

However, the fact of having substrates with extremely high water content probably will be an important condition and it might be a problem in order to attempt the viability of the project since high humidity will imply big treatment flows of VW.

Furthermore, while the fruits are substrates with a decent potential, both tomato and cucumber leaves (Table 7) as well as in the case of the willow (Table 9) have low methane efficiencies. In fact, this is due to the poorly biodegradable compounds such as lignocellulosic biopolymers that these kind of substrates contain (Edwiges et al., 2017). It also implies a problem because the fruits will be only a minority of the total biomass while the stalks and the leaves the big majority thus reducing the average methane efficiency of the biomass that will be entering to the plant.

Therefore, these GVW might be not as energetically efficient as VW from markets might be. These comments have been taken into account in further calculations.

Nonetheless, these substrates on batch assays have undergone a process of methane fermentation without the presence of agents that inhibit the process.

Further information can be find in the Annex B, presenting the average graphics of the fermentation process in the batch assays on melon and zucchini fruits as well as the evolutions of both biogas and methane accumulated during the experimental period.

In regards to the continuous fermentation test, it could not finish successfully since an inhibition of the process occurred and precluding to obtain accurate results of biogas efficiency and to estimate operational parameters from it. The inhibition of the test was probably provoked by a contamination of the samples since the three replications reacted the same way. However, the samples had a an average dry content and organic dry content of 9,06 % and 95,07 % with a 0,133 and 1,429 standard deviation respectively. Besides, HRT of 23 days alongside organic loading rates of 3 VS/m3·day were reached but as the process did not stabilize the HRT was estimated for the sizing of the digesters or to make any other conclusions.

In addition, changes in the qualitative composition of VW over time do not alter the homogeneity of parameters such as pH, TS and VS so the mixture of GVW represented in Almeria should not be a problem for the fermentation process. This indicates that VW is characterized by a standard acid level and high moisture and is rich in biodegradable compounds, regardless of the types of fruits and vegetables present in the mixture (Edwiges et al., 2017).

Further information can be find in the Annex C, presenting the average graphics of the simple continuous fermentation test on VW as well as the evolutions of both biogas and methane accumulated and the pH during the experimental period.

8. Biogas potential in the Almeria Province from GVW

Biogas is a combustible gas whose composition depends mainly on the type of substrate used and digested in the process. Its high concentration in methane with a high heat capacity (5.750 kcal / m3) gives it ideal fuel characteristics for its energy use being able to generate electricity, heat or be used as biofuels.

This section consists on evaluating energetically the GVW. Both the methodology and results are presented.

8.1 Inventory and quantification of substrates

The previous step of any study of energy potential, corresponds to the identification of the primary energy sources, from which the energy conversion will be carried out. The generation of vegetable wastes come from the eight main crops cultivated which are tomato, pepper, eggplant, cucumber, green bean, zucchini, melon and watermelon.

In order to do this, a model was established for the estimation of the seasonal biomass from the GVW taking into account the different crops in the area and the actual greenhouse surface, in order to finally estimate if there is enough biomass for the operation of the gasification plant.

The basis for the analysis of parameters of operation of biogas plants is to conduct the mass estimation of the substrates. It is necessary to specify the area of greenhouses (S) and its yield (Gp). Hence, the weight of the substrates to the management shall be calculated from the formula:

$$\mathbf{M = S \cdot Gp \quad [Mg]} \qquad \mathbf{[1]}$$

Where: M – mass of substrate [Mg]

S – area of the greenhouses [ha]

Gp – yield of the greenhouses [$Mg \cdot ha^{-1}$]

Table 10.- Greenhouse vegetable waste generation (leaves, stems and discarded fruits) for the eight main horticultural crops in the province of Almeria (López et al., 2016).

Type of vegetable waste	Mass of fresh residues (Mg/ha)	Area (ha)	Amount generated (Mg/year)
Tomato waste	73,3	10345	758288,5
Pepper waste	37	9326	345062
Eggplant waste	44,6	2446	109091,6
Cucumber waste	38,8	4979	193185,2
Greanbean waste	27,4	1439	39428,6
Zucchini waste	44,5	7369	327920,5
Melon waste	33,2	2946	97807,2
Watermelon waste	17	8378	142426
TOTAL			**2.013.209,6**

8.2 Biogas and methane production

Once the quantification of vegetables is completed, it should be clearly established how much biogas and methane it is possible to produce with the amount of bio-wastes available. This is done by a factor that indicates the productivity of the biomass, ergo, it indicates the amount of m^3 of biogas that can be obtained with a waste unit. Usually the amount of waste is measured in tons of organic matter but in the case it will be in tons of fresh matter, which will be the actual biomass (with water) that will be feeding the biogas plant.

In order to create the Table 10, an estimation was performed from experimental data (Table 6) taking into account the proportion of leaves, stalks and fruits on every crop. Further information encounters in the Annex D.

Then, the volume of biogas produced from the substrates (Vb) is calculated regarding the relationship between the biogas production efficiency and the mass of the substrates from this formula:

$$\mathbf{Vb = Eb \cdot M \quad [m^3]} \qquad \mathbf{[2]}$$

Where: Vb – volume of produced biogas [m^3]

Eb – biogas production efficiency [$m^3 \cdot Mg^{-1}$]

M – mass of substrate [Mg]

Obtaining the amount of m^3 de biogas produced, we proceed to obtain the amount of m^3 of methane contained in it. This is obtained by a factor that indicates the percentage of methane in the biogas produced. In turn, the volume of methane produced from substrates (VCH4) is calculated multiplying the volume of produced biogas (Vb) by the methane content ([CH4]) represented in the following formula:

$$\mathbf{VCH4 = Vb \cdot [CH4] \quad [m^3]} \qquad \mathbf{[3]}$$

Where: VCH4 – volume of produced methane [m^3]

Vb – volume of produced biogas [m^3]

[CH4] – methane content [-]

Biogas and methane production efficiency of the eight main vegetable wastes are presented in the Table 10 of the next page.

Table 11.- Biogas and methane production efficiency of the eight main vegetable wastes. Source: Own elaboration from experimental data.

Type of vegetable waste	Methane content [%]	Methane accumulated [m3/Mg]	Biogas accumulated [m3/Mg]
Tomato waste	44,42	14,44	32,5
Pepper waste	46,38	14,19	30,43
Eggplant waste	48,04	16,04	33,19
Cucumber waste	48,64	15,19	31,15
Greenbean waste	44,6	15,69	34,93
Zucchini waste	44,85	12,68	28,26
Melon waste	45,25	13,83	30,54
Watermelon waste	44,67	13,59	30,44

It should be added that in view of the fact that the gases have a different mass per volume at different temperatures and different pressures, the most accurate would be administrate the gas per unit of mass instead of volume. However, in practical terms and in a real working pipe, is much easier to measure the volume of gas flowing it through.

In addition, is important to keep in mind that in the real conditions of fermentation can occur synergies, which means that decreases the performance of the substrates even about 20-

30%. This effect is usually associated with insufficient quantities of some trace elements in some substrates, or their mixtures, which causes reduction of fermentation dynamics based on the mechanisms of acting according to Liebig's Law of the Minimum. At any rate, the theoretical amount of methane produced from different substrates has been calculated taking into account the biogas efficiency tests exclusively since the simple continuous fermentations turned to be invaluable. The formula regards the sum of the individual amounts of methane obtainable with single fermentation bio-wastes in play and the Figure 9 shows the results.

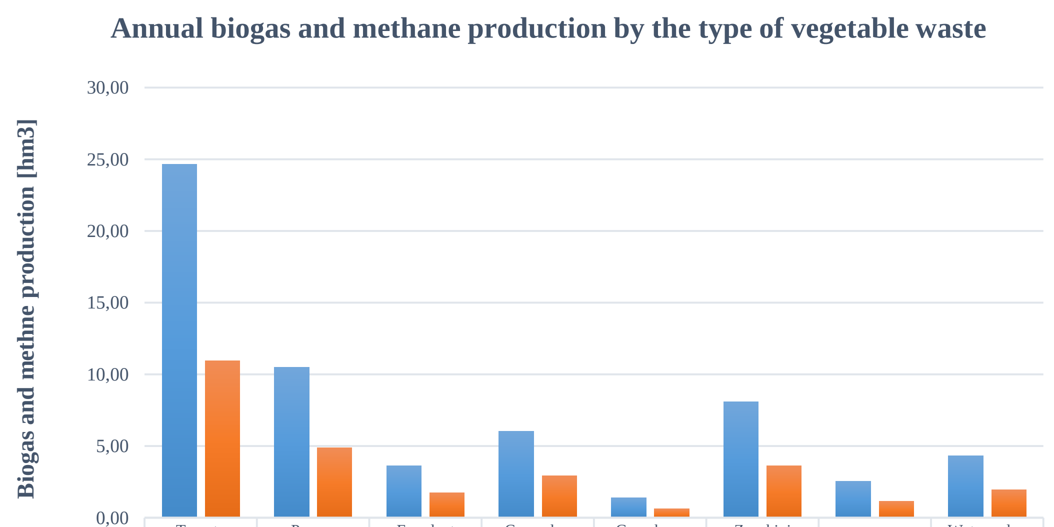
$$\mathbf{V_TCH4 = VCH41 + VCH42 + ... + VCH4n \quad [m^3]} \qquad \mathbf{[4]}$$

Where: V_TCH4 – the total volume of the produced methane [m^3]

VCH41 – the volume of methane produced by the susbtrate 1 [m^3]

VCH42 – the volume of methane produced by the substrate 2 [m^3]

VCH4n – the volume of methane produced by the substrate n [m^3]



	Tomato waste	Pepper waste	Eggplant waste	Cucumber waste	Greenbean waste	Zucchini waste	Melon waste	Watermelon waste
Biogas production [hm3]	24,64	10,50	3,62	6,02	1,38	8,10	2,54	4,34
Methane production [hm3]	10,95	4,89	1,75	2,93	0,62	3,64	1,14	1,94

Figure 9.- Biogas production and methane production of the vegetable wastes in fresh matter. Source: Own elaboration from experimental and data calculations.

The results showed a total annual biogas and methane production of **61.13 hm^3** and **27.87 hm^3** respectively with a methane average content of **46%**.

8.3 Electrical and thermal energy generation

Once the maximum and minimum available biogas and methane values are found, the respective calculations are made in order to find the amount of electrical energy that can be generated using the biogas produced in a cogeneration unit.

For conversion to the amount of energy produced, it is necessary to introduce the energy efficiency coefficient of methane equal to 0,00917 MWh/m^3 (9,17 kWh/m^3). To determine the amount of electricity produced in cogeneration, in addition, is mandatory to include the electrical efficiency of the co-generation unit (CHP (ηe)). Hereby the amount of produced electricity is calculated from this formula:

Ee = VCH4 · ReCH4 · ηe [MWh] **[5]**

Where: Ee – quantity of electricity produced in cogeneration [MWh]

VCH4 – volume of methane produced [m^3]

ReCH4 – energy efficiency coefficient of methane [0,00917 $MWh \cdot m^{-3}$]

ηe – electrical efficiency of cogeneration unit [-]

ηe = 0.36-0.44 [-]; *It takes the value of 0.4*

Similarly as in the case of electricity, the amount of heat energy produced in cogeneration is calculated from the following dependencies:

Et = VCH4 · ReCH4 · ηt [MWh] **[6]**

Where: Et – the amount of heat produced in a cogeneration [MWh]

VCH4 – the volume of methane produced [m^3]

ReCH4 – energy efficiency coefficient of methane [0.00917 $MWh \cdot m^{-3}$]

ηt – thermal efficiency of cogeneration unit [-]

ηt = 0.43-0.54 [-], It takes the value of 0.48

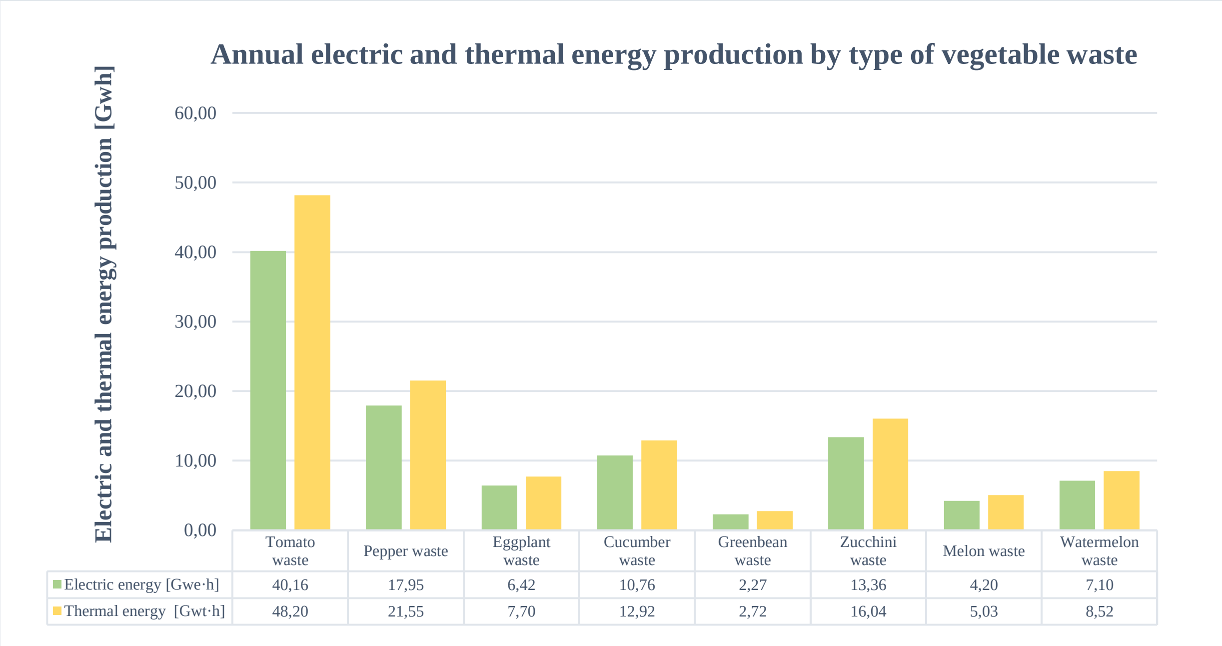


Figure 10.- Electric and thermal annual energy production by type of vegetable waste in fresh matter. Source: Own elaboration from experimental data and calculations.

Once the respective energetic conversions were made, the graph of the Figure 10 was drawn up, which indicates the amount of annual electric energy that can be generated with each analyzed vegetal waste resulting to a total annual electric and thermal energy production of **102.23 GWh** and **122.68 GWh** respectively. The total energy potential counting the losses (12%) amounts to **255.57 GWh.**

It is possible to observe that the type of vegetal waste with greater energetic potential in the greenhouses of Almeria corresponds to the wastes from the production of tomatoes because of its huge availability. These have an annual electrical and thermal production of 40,16 Gwh/year and 48,20 Gwh/year respectively, reaching about 40% of energy production of the total vegetal waste of Almeria.

In view of the fact that in the practice is more often give the amount of heat per Gigajoule [GJ] than Gigawatts hour [GWh], knowing that 1 GJ is equal to 0,274 MWh, we can easily convert the energy expressed to GJ according to the following equation:

Et [GJ] = Et [GWh]/0,274 [GJ] **[7]**

Where: Et [GJ] – quantity of produced thermal energy expressed in [GJ]

Et [GWh] – quantity of produced thermal energy expressed in [GWh]

The annual thermal energy production expressed in GJ resulted to **447,72 GJ/year**

The following diagram shows the process of gasification of the GVW to obtain electrical and thermal energy and the values used for the calculations:

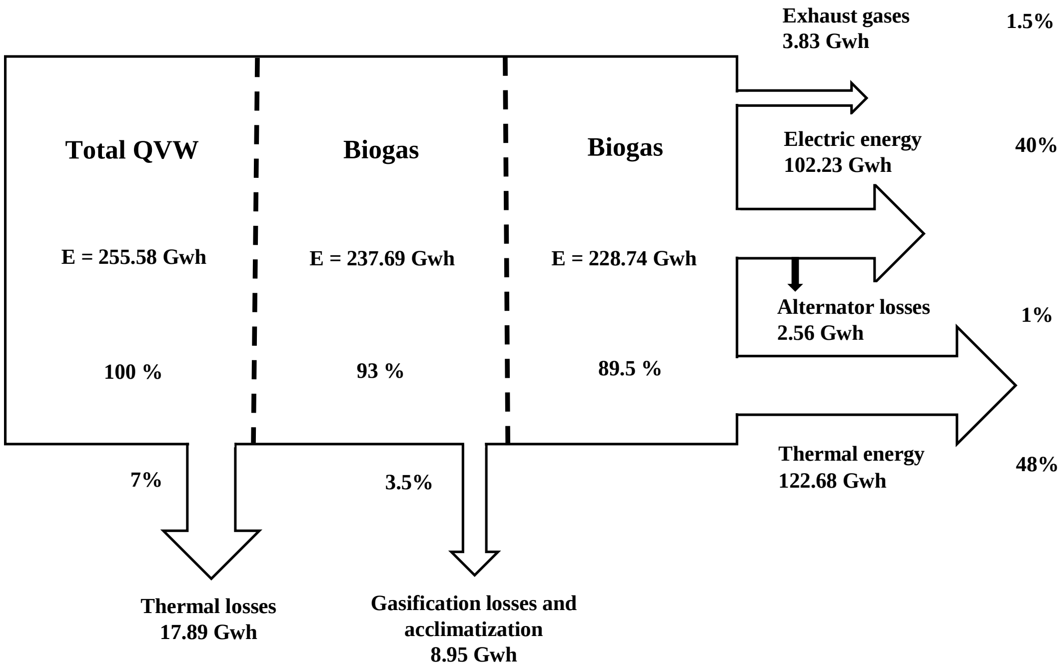


Figure 11.- Sankey diagram of the process of gasification of GVW to obtain electrical and thermal energy. Source: Own elaboration.

8.4 Electrical and thermal power generation

The next step is the calculation of the installable both electrical and thermal power produced in a cogeneration unit assuming annual average time of its work. A typical year (non-leap) has 8760 hours. However, the cogeneration unit is based on the internal combustion engine which requires periodic maintenance services (e.g. oil change, spark plugs, etc.) and some repairs from breaks. Hence, it is assumed that a typical cogeneration unit should work per year approximately 8200 hours. On this basis, we can calculate the power of the electric generator from the following dependencies:

$$\mathbf{Pe = Ee / t \ [MW]} \qquad \mathbf{[8]}$$

Where: Pe – electric power of the biogas plant [MW]

Ee – quantity of electricity produced in cogeneration [MWh]

t – operation time of cogeneration unit [h], ~ *8200 [h]*

By analogy from the electric power we enumerate the thermal power on predefined substrates:

$$Pt = Et / t \text{ [MW]} \qquad \textbf{[9]}$$

Where: Pt – thermal power [MW]

Et – quantity of produced thermal energy [MWh]

t – operation time of cogeneration unit [h], ~ *8200 [h]*

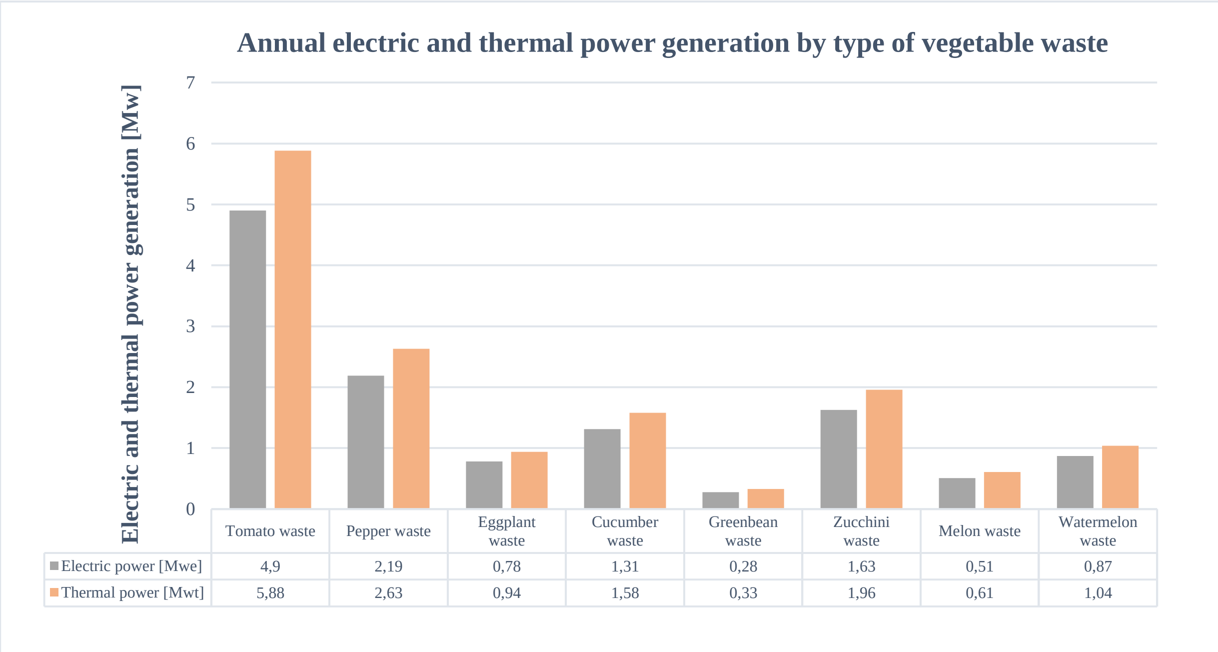


Figure 12.- Electric and thermal annual power production by type of vegetable waste in fresh matter. Source: Own elaboration from experimental data and calculations.

The results showed an total annual electric and thermal power production of **12,47 GW** and **14,96 GW** respectively. The total power potential counting the losses (12%) amounts to **31,17 GW.**

9. Greenhouse – biogas plant system

9.1 General model

In this very particular case is desired to implement a Greenhouse – biogas plant system operating with the GVW from these outstanding conglomerate of greenhouses in the Almeria Province (mainly in those under strict climate control) producing both electric and thermal energy. Besides, it comes the innovative idea of implementing a CO_2 recovery system on its generation in the co-generation after biogas combustion. Hence, two bonus are added to the benefits of this idea since the CO_2 pumping to the very greenhouses will improve plant growth and the biofertilizer usage implies a cost reduction for the greenhouses owners.

As a result of the anaerobic digestion a digestate is generated that presents a richness in organic matter and nutrients for the soil which maintains the nutrient concentration (NPK) of the feed and presents a high degree of mineralization, which translates into greater availability for cultivation.

The re-use of GVW as a source of heat and CO_2 would not only eliminate an environmental problem, but also raise the temperature in the cold periods and the concentration of CO_2, which are usually below the optimum (López et al., 2008; Sánchez-Guerrero et al., 2005). This could lead to a production increase of around 15%, as shown by different experiences in the area with the use of heating (López et al., 2008) or CO_2 enrichment (Sánchez-Guerrero et al., 2005). And very significant increases when both techniques are combined (Sánchez-Guerrero et al., 2005).

The main assumptions of the system are as follow:

a. Produced biogas should be combusted in co-generation unite;
b. Electric energy will be sold directly to the grid;
c. Thermal energy will be used for greenhouse heating; (Esen M. et al., 2013) (Qi X. et al., 2005);
d. Exhausted gases from cogeneration unit (mainly CO_2 and N_2) will be used for increasing CO_2 level inside the greenhouse in order to accelerate plant growing process (Janczak et al., 2016);
e. Digestates from fermentation will be used as ecological fertilizer by the greenhouses;

f. Vegetable waste from greenhouse will be used as substrates for biogas plant;

In the Figure 13 the general model is presented:

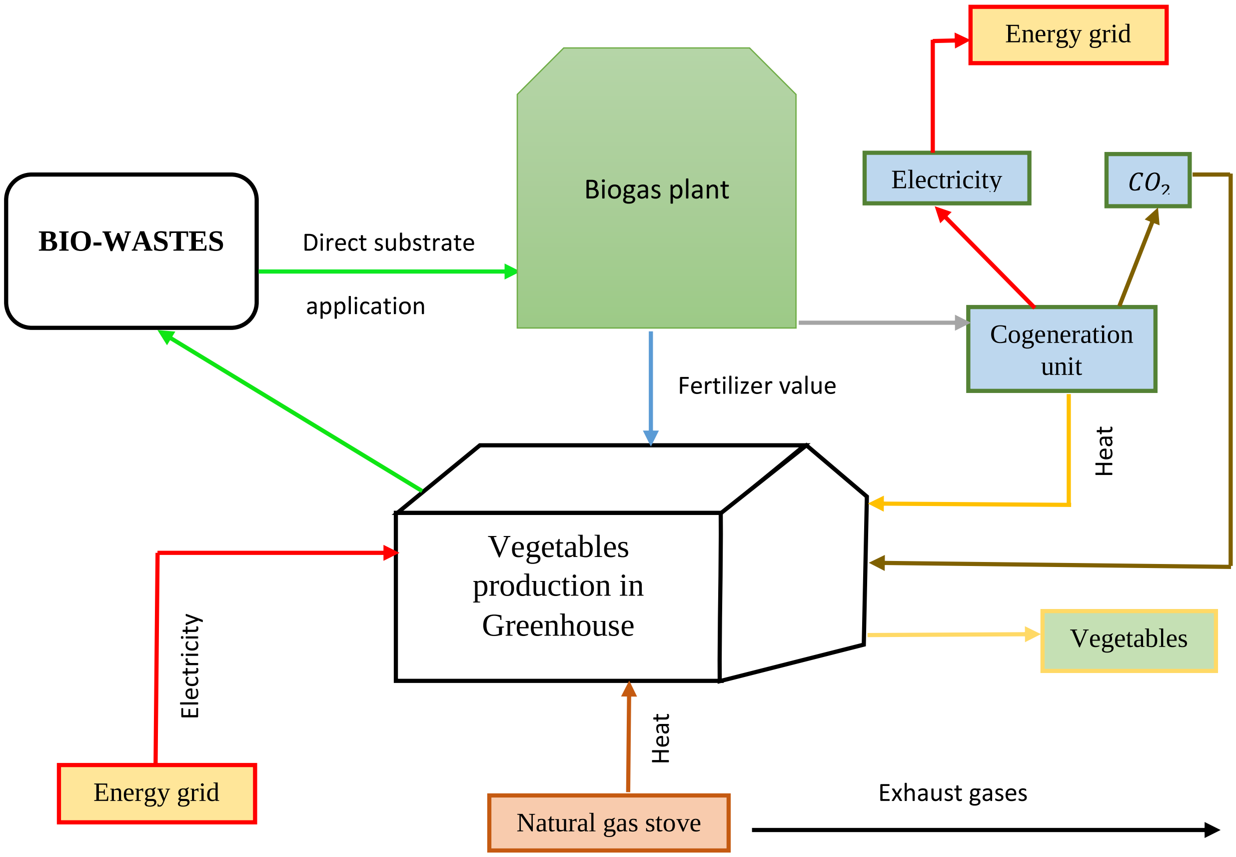


Figure 13.- The idea of a complex system greenhouse – biogas plant. Source: Own elaboration.

9.2 Definition of the installation

Figure 14 shows an outline of an anaerobic digestion plant. In it you can see the main areas of work.

Figure 14.- Model of biogas plant for anaerobic digestion (ARC, 2017).

9.2.1 Anaerobic digestion zone: Dynamic Biogas Technology (number 6 of Figure 14)

Some of the questions that will determine which type of digester is the most appropriate to treat the type of waste object of study are the capital for investment, the quality of the biogas to be generated and the raw material to be introduced into the digester.

The patented Dynamic Biogas Technology (DBT) taken from the Swiss company *Dynamic Biogas* is one of the world's most advanced systems for creating electricity from the fermentation of wide range organic materials and is developed to maximize the biogas yield with higher methane content for efficient use in on-site power generation. It has been already proved in Poland with excellent results using agricultural wastes and multiple laboratory experiments assert its accelerator reliability (number 3 of Figure 15).

This type of plant makes possible to degrade even the cellulosic elements with ease by separating the hydrolysis from the bottom of the process and it has been proven recently in biogas plant already operating. The following illustration shows the basic schema of a dynamic biogas plant.

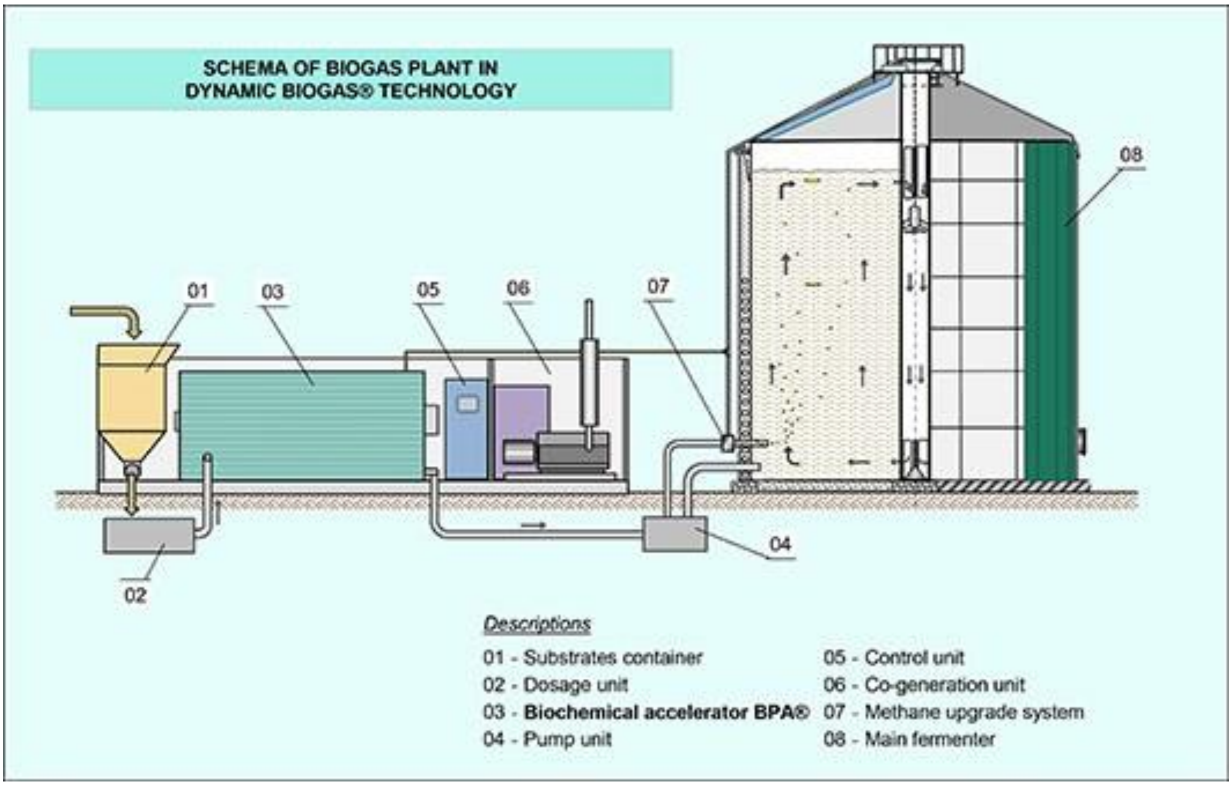


Figure 15.- Schema of biogas plant in dynamic biogas technology (Dynamicbiogas.com, 2018).

As references, experiments in the application of enzymatic hydrolysis in algae biomass as a pretreatment for biogas production turned out to be highly effective. The process triggered to release a considerable quantity of carbohydrates becoming more available and more rapidly by the microorganisms during the process of fermentation (Grala et al.,2012). On the other hand, a 15% increase in the biogas production was determined in a reactor containing a bio-enzymatic preparation in comparison with a reference reactor (Vítěz et al., 2011).

The main characteristics of this type of bioreactor operating currently in Poland as well as the explanation of its process of operation and its advantages over conventional biogas plants are detailed in the Annex E.

9.2.2 Building services and offices (number 1 of Figure 14).

In it are installed the necessary computer equipment for the management of the plant and it will be in charge of receiving the waste that arrives to the plant.

9.2.3 Substrates storage area (numbers 2 and 3 of Figure 14)

Vegetable wastes do not need a special container since they are solid and they can be stacked and handled by common machinery. It identifies a solid waste storage area, properly limited and it will have a recovery system of possible leachates that are generated for later use in the digester. This zone will act as a buffer, since it will allow to introduce the residue little by little in the digesters. Some examples are shown in Figure 16.

Figure 16.- Examples of storage of plant residues.

9.2.4 Pretreatment and mixing of wastes (number 4 of Figure 14)

In this area of the installation the residue must be subjected to a pretreatment so that in the digestion process the maximum possible yield in the generation of biogas is obtained. It is important for its degradation by the microorganisms, that the residues present a composition as homogeneous as possible. This will facilitate their work and it will not act as a limiting factor.

According to the testes executed in Poland the vegetable wastes would not require a previous grinding before entering to the digester with this kind of technology because the biochemical hydrolyzer process is very effective and powerful (number 3 of Figure 14). Nonetheless they still have to be chopped with a size between 6 and 10 mm so that their silage is optimal. Carrying out a chemical pretreatment is not advisable, since in this particular type of waste, it contains residues of pesticides and other compounds that when interacting with the pre-treatment chemical compounds can form toxic compounds.

In addition, plastics as greenhouse covers, drip irrigation pipes, sacks, fertilizer bags, containers, transport and planting trays, among others and metals as wires are likely to join the GVW. All these elements will act as inhibitors of the anaerobic digestion process, so it is necessary that this fraction be nonexistent or as small as possible. To this end, it will be important to raise awareness on the part of the farmer and his workers. Nonetheless, it would be possible to implement also a zone of elimination of these elements through the trommel to residues of a lower density (plastic), densimetric tables to inerts and a magnetic separator to metals although it would increase the price of investment.

9.2.5 Digester feed (Number 5 of Figure 14)

A hopper feed tank connected to a piping system. At present, thanks to the control systems of the plants, this is done automatically and very accurately, so a continuous feeding is achieved.

9.2.6 Digestate storage area (numbers 8 of Figure 14)

Covering the digestate storage area with a membrane will allow also to store biogas which is still produced post-fermentation (even if little) from the digestate making this very cover act as gasometer as well.

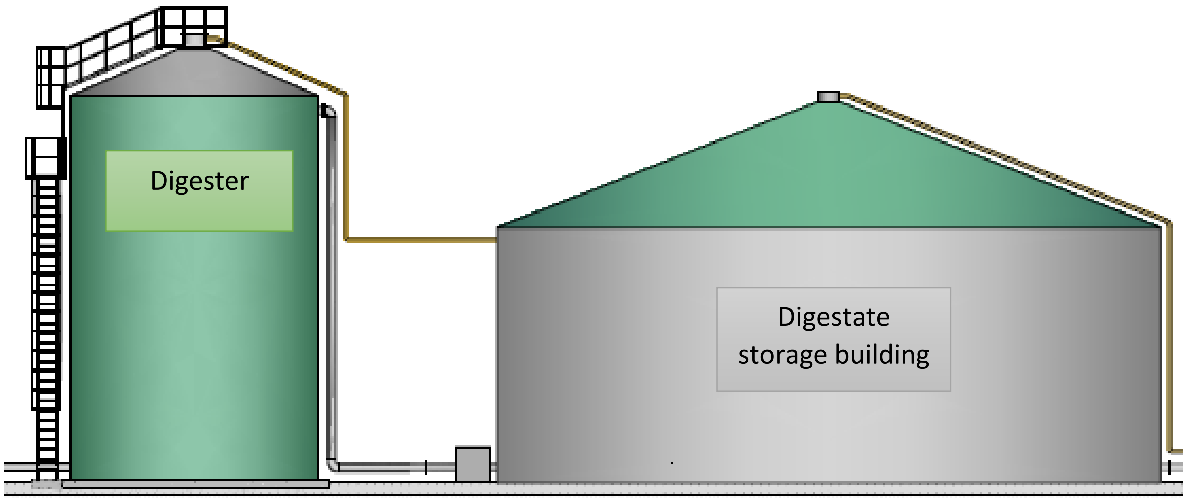


Figure 17.- Biogas digester plus the biogas/digestate storage area.

9.2.7 Biogas storage area (number 10 / 8 of Figure 14)

At first, as aforementioned, the biogas should be stored at the same tank the digestate is being stored. Nonetheless, among the most used are dome or floating hood on water tank that can reach important storage volumes, although usually do not exceed 1500 m^3 and the pressure normally does not exceed 50 mbar. Another option also widely used are inflatable gasometers.

9.2.8 Biogas conditioning by dehumidification and contaminants removal (number 12 of Figure 14)

Conditioning the biogas to meet the basic requirements of the cogeneration unit as well as to achieve the best yields and to reduce the impact of the gaseous emissions is mandatory.
To inject the biogas to the cogeneration unit it is necessary to maintain a level of pressure that ensures the necessary provision. For this a compression unit is used and this parameter will depend on the generating unit selected.
Furthermore, reduction in water content is beneficial to the CHP system and increases the energy content of the gas. An efficient dehumidification allows also to reduce the concentration of components such as hydrogen sulphide, siloxanes, ammonia and halogen compounds which dissolve in the condensed water. The partial or complete removal of these contaminants improves the efficiency of the whole plant and greatly reduces maintenance costs and plant downtime.
There are many technologies for water vapor removal but the cooling system is the most common to condense water in such installations. Nonetheless, if it is still needed to remove more contaminants, connected to the cooling system are active carbon filters (high efficiencies (> 95%).

Figure 18.- Cooling system connected to a H_2S and siloxanes removal. Source: Taken by myself.

9.2.9 Cogeneration system - CHP (number 13 of Figure 14)

Cogeneration is defined as the simultaneous production of electric and thermal energy using the same fuel. The main advantage of cogeneration compared to conventional electricity generation systems is that it has a higher energy efficiency in the process.

The systems to carry out the cogeneration are very varied: alternative internal combustion engines, microturbines, steam or gas turbines, Stirling engines or Rankie cycles.

The electric power of the CHP generator relies on the characteristics of the substrates of the digester and consequent capacity of the biogas produced.

9.2.10 CO2 recovery zone

The use of CO_2 after biogas combustion will allow us to replace expensive systems of liquid CO_2 currently used in such greenhouses (Figure 19). The aim stands in the injection of larger amounts of CO_2 to the greenhouse in order to increase its concentration up to the level of 1000 ppm.

Figure 19.- CO_2 storage and evaporator circuits for carbonic enrichment in greenhouses is the current system used in modern greenhouses in the province of Almeria (Valera et al., 2014).

The 94% of the greenhouses are configured under low cost investment whilst the 6% remaining are industrial greenhouses with high climate control (Residuos vegetales procedentes de los invernaderos de almería, 2016). Therefore, the carbon dioxide will be fed only to industrial greenhouses which will be able to actually benefit from the advantages of pumping it.

9.3 Anaerobic digestion starting

The anaerobic microorganisms present a slow growth, especially the methanogenic bacteria, therefore during the starting of the anaerobic systems a bacterial inoculum is usually used. This inoculum corresponds to a sludge that already possesses a population of microorganisms capable of initiating the anaerobic degradation process.

Therefore, sufficient volume must be available for the inoculation - 10-30% of the reactor volume (Cubero, 2011) -. The selection of a suitable inoculum will be essential to obtain a rapid start and decrease the time required for the formation of the bacterial joints necessary for the development of an anaerobic process.

9.4 Seasonality problem

In relation to the seasonality problem of the waste it would not affect the biogas plant functioning. Nowadays with the greenhouse system agricultural residues of this type are generated throughout the year. It may happen that the amount of a specific crop decreases, but another will increase, which can act as a substitute.

9.5 Location of the installation

The geographic location should be searched by using GIS (Geographic Information System) techniques.

First obtaining possible areas in Poniente Almeriense depending on the distance to main communication routes as well as distances to high voltage power lines. It is a critical factor because the greenhouses must be within reach of the plant easily either to minimize transport costs of GVW to the plant as well as to make the thermal energy produced by cogeneration accessible to the greenhouses.

Secondly eliminating those areas that have some type of restriction as for example urban influence or being a predefined use zone.

Finally evaluating the remaining solutions with criteria of proximity to certain resources such as surface hydrology and greenhouse nuclei.

See the Figure 20 to visualize the diagram of the process.

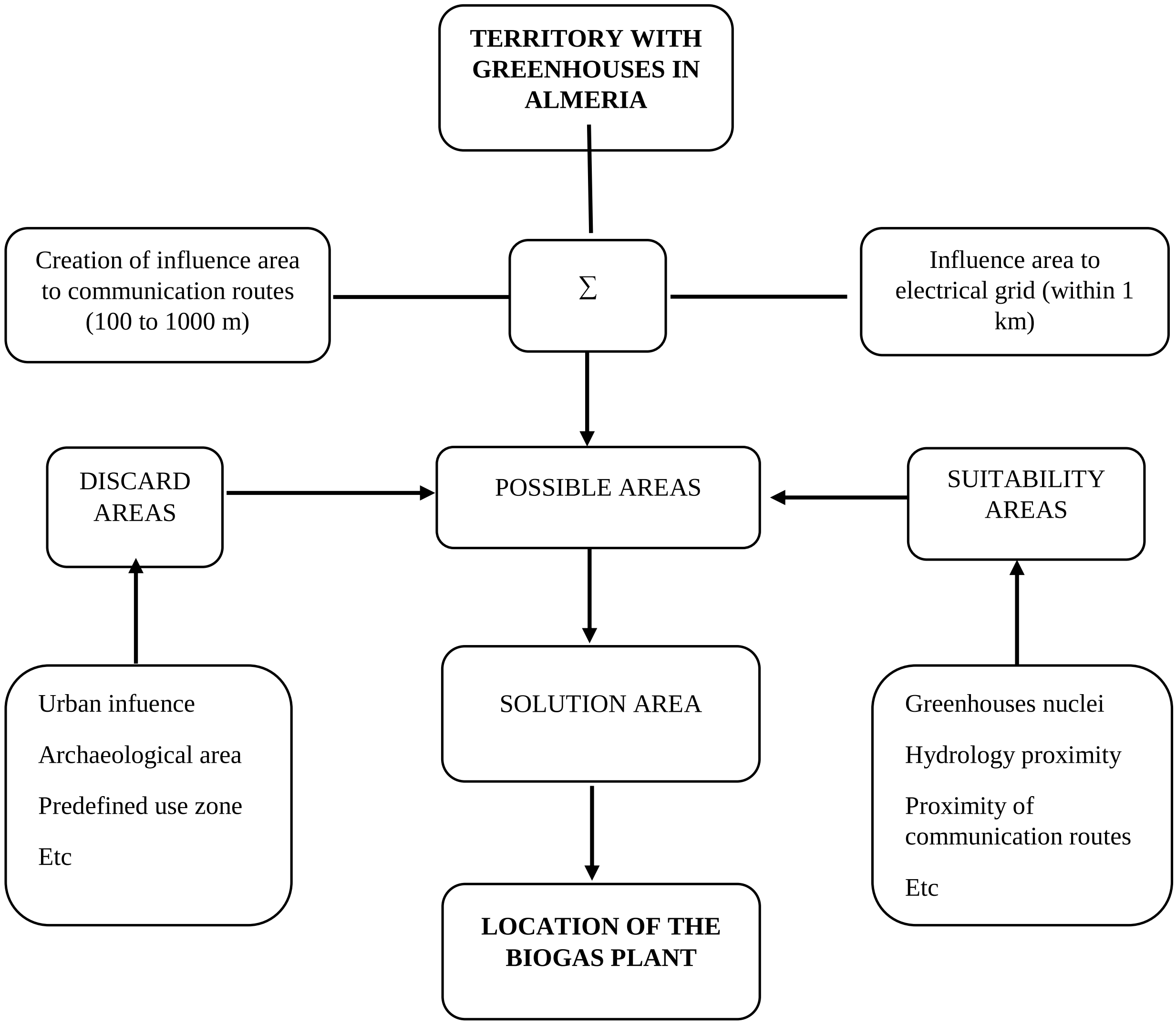


Figure 20.- Diagram of the process to determine the biogas plant location.

10. Economic evaluation

10.1 Starting data

TRH hydraulic retention rate depends on the characteristics of the each waste. One of the goals of the continuous fermentation test was to determine this parameter but since the experimental tests resulted unfavorable, it is estimated according to the temperature of the location. According to data from the National Institute of Statistics, in Almeria the average temperature is around 20 ° C, with an average of 138 days at a temperature equal to or above 25 ° C (taking data from 1997 to 2012).

According to the Figure 21 the correction factor for the hydraulic retention time take a value of 2,00.

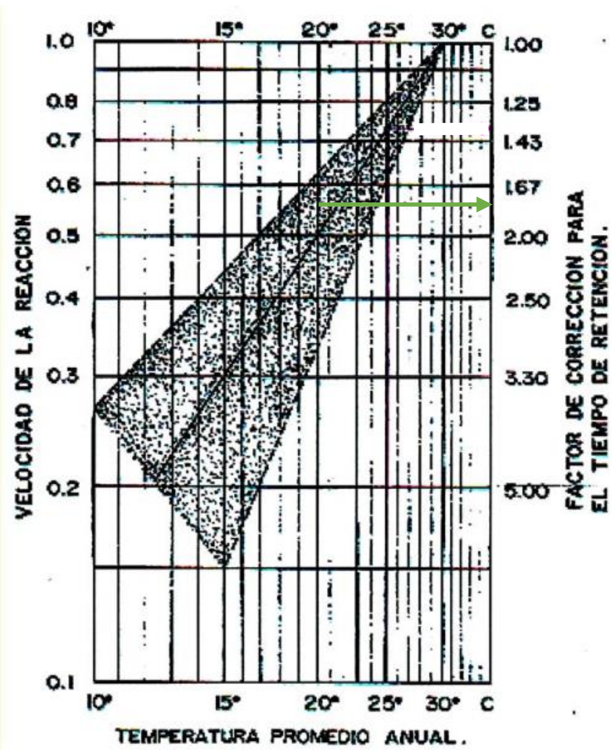


Figure 21.- Reading the correction factor for the retention time.

The hydraulic retention time (HRT) is calculated from the following dependencies:

$$\boldsymbol{HRT = CF \cdot HRT_I} \quad \textbf{[days]} \qquad \textbf{[10]}$$

Where: HRT – hydraulic retention time [days]

CF – correction factor [-]

HRT_I – ideal hydraulic retention time [days]

According to the results of biogas production tests we know that we cannot technically build a biogas plant of 500 KWe or 1 MWe because the biomass to treat would be too big and to build the installation would be impossible. Therefore, in base of the volume of the digesters (for example 4 digesters accounting 2000 m^3) we will calculate the electrical power we can obtain with the following dependencies:

$$\boldsymbol{TF = VD/HRT} \quad [\mathbf{m^3/day}] \qquad \textbf{[11]}$$

Where: TF – treatment flow [m^3/day]

VD – volume digesters [m^3]

HRT – hydraulic retention time [days]

Is considered that the biomass has a density equivalent to that of water since the substrates are mainly water. Hence the mass of annually biomass is:

$$\mathbf{My'} = \boldsymbol{TF \cdot t} \ \textbf{[Mg]} \qquad \textbf{[12]}$$

Where: My'– mass of the substrate needed to supply the biogas plant for a year [Mg]

TF – treatment flow [Mg/day]

t – operation time of cogeneration unit [h], ~ *8200 [h]*

Finally, the electric power of the biogas plant is calculated:

$$\mathbf{Pe = (My' \cdot Em \cdot \ ReCH4 \ \cdot \ \eta e)/t} \, [\mathbf{MWe}] \qquad \textbf{[13]}$$

Where: Pe – electric power of the biogas plant [MW]; 100 KWe

My'– mass of the substrate needed to supply the biogas plant for a year [Mg]

t – operation time of cogeneration unit [h], ~ *8200 [h]*

Em – methane production efficiency [$m^3 \cdot Mg^{-1}$]

ReCH4 – energy efficiency coefficient of methane [0.00917 MWh* m^{-3}]

ηe – electrical efficiency of cogeneration unit [-]; 0,4

Table 12.- Starting data for the economic evaluation.

Parameter	Value
Hydraulic retention time [days]	40
Volume reactor [m3]	2000
Treatment flow [m3/day]	50
Mass of substrates [Mg/year]	17083
Electrical energy generation [MWh]	877
Electrical power [KWe]	107
Thermal power [KWt]	128
Thermal energy generation (Eh) [Gj]	3840
Biogas production [m3/year]	524993
Mass of digested [Mg/year]	15375
Mass of CO2 generated [Mg/year]	997

Therefore, this section will tackle the economic issue of installing a 107 KWe of electric power and biogas plant previously designed. According to the reports provided by different companies and according to the experience in the sector, the useful life of a biogas plant has been estimated accounting to 20 years (evaluation horizon).

First of all the methodology will be explained and finally the results will be presented. Further details of the cash flow can be found in the Annex F.

10.2 Investment

This considers the gasification and cogeneration equipment as well as civil works (construction of ponds, piping, gasometers, engine room, silos, CO_2 pumping equipment and minor works). It should be noted that the initial investment includes the acquisition, installation and commissioning of equipment. Due to possible unforeseen and inaccuracies in the investment calculation, it is appropriate to consider a contingency amount equivalent to 15% of the total investment. It finally accounts to **2.300.000 euros**.

10.3 Cash – flow

To perform the cash – flow the costs and revenues, as well as other elements of this, such as depreciation of the installation and taxes, should be analyzed separately and thus estimating the annual gross profit.. From here is formulated the following relation:

CF = AR – AC – T + D [EUR] **[14]**

Where: CF – cash – flow or annual profit from the exploitation [EUR]

AR – annual revenue in the biogas plant exploitation [EUR]

AC – annual costs in the biogas plant exploitation [EUR]

T – annual taxes in the biogas plant exploitation [EUR]

D – annual depreciation in the biogas plant exploitation [EUR]

10.3.1 Revenues

The biogas plant processing the bio-wastes from the greenhouses of Almeria will be built on the sale of electricity, thermal energy, digestate, carbon dioxide and carbon certificates. Hence, on this basis, we can specify the following equation:

AR = ARee + ARet + ARpp + ARCO2 + ARcc [EUR] **[15]**

Where: AR – annual revenue in the biogas plant exploitation [EUR]

ARee – annual income from the sale of electricity [EUR]

ARet – annual income from the sale of thermal energy [EUR]

ARpp – annual income from the sale of digestate [EUR]

ARCO2 – annual income from the sale of CO_2 [EUR]

ARcc – annual income from the sale of carbon certificates [EUR]

10.3.1.1 Revenue from electricity generation

The annual revenue only depends on the price established in the wholesale Spanish electricity market. The electricity selling price to the wholesale market is constantly fluctuating and volatile but according to RD 413/2014 of June 6, which is regulated the activity of production of electric energy from renewable energy sources, cogeneration and waste treatment, the market price is set to 52 EUR $\cdot$ MWh^{-1} from 2015 and onwards.

Furthermore it will be taken into account an especial tax (IVPEE) of a 7 % on the value of energy production established by the Spanish government and that the 5% of electric energy will be used for the own consumption of the installation:

$$\mathbf{ARee = Ee \cdot pe \cdot 0,95 \cdot 0,93\ [EUR]} \qquad \mathbf{[16]}$$

Where: ARee – annual income from the sale of electricity [EUR]

Ee – quantity of electricity produced [MWh]

pe – estimated selling price of electricity [EUR · MWh^{-1}]; *52 [EUR · MWh^{-1}]*

0.95 – coefficient of the real sale of electricity [-]

0.93– coefficient of reduction for special tax for energy production [-]

10.3.1.2 Revenue from thermal energy generation

Looking for opportunities to take advantage of thermal energy - along with electrical energy - can bring revenues that justify the installation of a project. Under certain conditions the selling price of thermal energy (EUR / MWh) will be lower than that of other fossil fuels. The revenue from the thermal energy produced depends on the amount of heat produced and its price. There are no prices for the sale of thermal energy in Spain, but the closest is the comparison with the price of natural gas and propane for industrial customers. These prices are 50 and between 80 and 140 [EUR/MWh] respectively (Página de Preciogas, 2017). If it is sold at a price of 30 EUR / MWh entails a competitive and considerably much lower comparing with the habitual fuels prices. It should be noticed that the 5% is used for the own consumption of the installation since the fermenters must be heated. Hence, this revenue is calculated with the formula:

$$\mathbf{ARet = Et \cdot pt \cdot 0,95 \cdot 0,93\ [EUR]} \qquad \mathbf{[17]}$$

Where: ARet – annual income from the sale of thermal energy [EUR]

Et – quantity of thermal energy produced [GJ]

pt – selling price of thermal energy [EUR · GJ^{-1}]; *8,22 [EUR · GJ^{-1}]*

0.95 – coefficient of real sale of thermal energy [-]

0.93– coefficient of reduction for special tax for energy production [-]

10.3.1.3 Revenue from digestate generation

We know the mass of digestate decreases in fermentation by about 7 – 10% from the initial value of substrate as a result of biogas emissions. After the process practically the 100%

of the digestate will be liquid and thus becoming to a high quality fertilizer. Hence, the mass digestate can be calculated according to the equation:

$$\mathbf{Md = M \cdot \eta f \ [Mg]} \qquad \mathbf{[18]}$$

Where: M – mass of the substrate for biogas plants [Mg]

ηf – coeficient of weight maintainance after fermentation [-]; *a value of 0,90 has been taken*

Due to the high degradation efficiency of the wastes in the process, the solid fraction is virtually negligible. Hereby, this digestate appears to be a very good candidate to replace inorganic fertilizers, also contributing, to the short-term soil organic matter turnover (Tambone et al., 2010).

The revenue from digestate is supposed to be calculated from its value based in mineral content since the price allocated to the recovered nutrients is in accordance with the market price of N, P and K in mineral fertilizers. Unfortunately, we do not dispose of the lab devices to conduct the NPK analysis from our samples to reach a sharp accuracy on the results and reliable data from references has been not found. For this reason, knowing that the annual costs from fertilizers in the Almeria greenhouses entails the 7 % of the total costs for the farmers (Valera et al., 2014), their current annual total costs have been estimated resulting to 28,8 [EUR/ha] and 14,42 [EUR/Mg] (the estimations are in the Annex G). On this basis, the value of the digestate has been established as the half of fertilizers price that they are currently using in order to promote this new product (7.21 [EUR/Mg]). Revenues are calculated according to the formula:

$$\mathbf{ARpp = Md \cdot pd \ [EUR]} \qquad \mathbf{[19]}$$

Where: ARpp – annual income from the sale of biofertilizer [EUR]

Md – mass of biofertilizer produced [Mg]

pd – selling price of the biofertilizer [EUR · Mg^{-1}]

The greenhouses of Almeria are consuming in average around 2.000 kg/ha of mineral fertilizers, reaching in some cases up to 3.400 kg/ha (Ramos-Miras, 2002). It means a consumption between 58.000 and 98.600 Mg per year in the 29.000 ha. It means that the 15.375 Mg of biofertilizer produced annually in the biogas plant would replace 20% of the whole annually demand.

10.3.1.4 Revenue from CO2 generation

Revenue obtained from the use of CO_2 pumped to the greenhouse can be calculated on the basis of the costs currently incurred by the greenhouse.

By way of extension, it should be noted that the starting price for CO_2 is between 0.10 € / kg and 0.19 € / kg, when maximum purity (required for the food industry) is reached. Therefore, a value of 100 € / Mg CO_2 (the minimum to be competitive in the market) was taken in order to calculate the revenues from CO_2 recovery. The value of the carbon dioxide produced by the cogeneration unit and used in the greenhouse will be thus calculated from the formula:

$$\mathbf{ARCO2 = MCO2 \cdot CCO2\ [EUR]} \qquad \mathbf{[20]}$$

Where: ARCO2 – annual income from the sale of CO_2 [EUR]

MCO2 – mass used in greenhouses as CO_2 [Mg]

CCO_2 – selling price of CO_2 [$EUR \cdot Mg^{-1}$]; *100 [EUR/Mg]*

To calculate the masss of carbon dioxide generated we need to know that after burning one molecule of methane is formed to one molecule of carbon dioxide. Hence, stoichiometrically counted number of molecules of carbon dioxide in the flue gas will be equal to the sum of the molecules of methane and carbon dioxide in the biogas before combustion.

It is assumed that the average time to deliver CO_2 to the greenhouse is 8 h/day (this is the time of the most intense assimilation of carbon dioxide during the intense sun exposure). Hence, we must take into account that only 1/3 parts of the day the CO_2 produced in CHP will be pumped to the greenhouses. It accounts to 2432 h annually.

$$\mathbf{MCO2 = Vb \cdot \varrho CO2\ [Mg]} \qquad \mathbf{[21]}$$

Where: MCO2 – mass of carbon dioxide produced after combustion [Mg]

Vb – volume of biogas produced [m3]

ϱCO2 – density of CO2 0,001842– 0,001977 [$Mg\ m^{-3}$]

10.3.1.5 Revenue from carbon credits

Carbon credits are an international decontamination mechanism to reduce emissions to the environment; it is a trading system through which the various agencies involved can sell or acquire emission reduction certificates (CERs). One CER corresponds to one metric ton of carbon dioxide equivalent and the market offers a solution to reduce the effects of this phenomenon since greenhouse gases are quantified in the same unit. Although this type of emission reductions are highly critical, it is the current way in which it is tried to control the gases of greenhouse effect. This analyzed project will be able to sell CERs since non carbon dioxide emissions are released to the atmosphere. According to Kantor (2005), a good project raises the rate of return of investment between 10 and 30% per year. However, it is not ruled out that a few more years later another system is chosen.

If we have a look of the price of carbon certificates in the market in 2017, we can see that it has declined considerable reaching a value of 25 $EUR \cdot Mg^{-1}$ (IETA, 2017). It is due to two factors: overpopulation of carbon credits and European recession - one of the main customers of CERs -. Nonetheless, according to forecasts, depending on the purpose of reducing emissions to be adopted by Europe for 2020, its price will increase enormously thus encouraging to invest in this kind of projects again. For this reason, since the project is intended to be implemented in a far future in a scenario with new favorable conditions, in this project we will assume a carbon certificates 5 $EUR \cdot Mg^{-1}$ of carbon dioxide equivalent and from 2023 and on, we assume a value of 20 $EUR \cdot Mg^{-1}$.

$$\mathbf{ARcc = MCO2 \cdot pcc\ [EUR]} \qquad \mathbf{[22]}$$

Where: ARcc – annual income from carbon certificates [EUR]

TMCO2 – total mass of CO_2 [Mg]

pcc – selling price of carbon certificates; *5 [EUR · Mg^{-1}] until 2023 and 20 [EUR · Mg^{-1}] from 2023 and beyond.*

10.3.2 Costs

The annual costs of biogas plants in simplified terms, include the costs of substrates, operation, service, technological support and staff:

$$\mathbf{C_{abi} = Csale + Csubr + Cop + Cserv + Cdepr + Cstaff\ [EUR]} \qquad \mathbf{[23]}$$

Where: C_{abi} – annual cost of biogas installation [EUR]

Csale – cost of sale [EUR]

Csubr – cost of substrates [EUR]

Cop – cost of operation [EUR]

Cserv – cost of services [EUR]

Cstaff – cost of staff [EUR]

10.3.2.1 Cost of sale

Cost of sale includes tolls for acces to the transmission and distribution grids: Fortunately this plant will not be subjected to them because it does not exceed 1 MW. You will find further information about this toll in the Annex H.

On the other hand, the costs of transmission of thermal energy are not considered since the analysis required for the demand of thermal energy is only relevant to nearby locations, since the sale of heat - in the form of hot water or hot steam (number 15 of Figure 14) - is not justified by operational costs and heat dissipation for distant customers.

Nonetheless for the sale of carbon credits it is first necessary to certify the validity of these and then look for a buyer in the market. This means using both time and resources of the company. Given the difficulty of accurately calculating the cost of this work, it will be valued as a percentage of the revenues from the sale of carbon credits equivalent to 40%.

$$\mathbf{Ccc = ARcc \cdot 0.4\ [EUR]} \qquad \mathbf{[24]}$$

Where: Ccc – costs of carbon credits selling [EUR]

ARcc – annual income from carbon certificates [EUR]

0,4 – coefficient of investment [Mg]

$$\mathbf{Csale = Celtrans + Ccc\ [EUR]} \qquad \mathbf{[25]}$$

Where: Csale – cost of sale [EUR]

Celtrans – cost of electric transmission [EUR]

Ccc – cost of carbon credits sales [EUR]

10.3.2.2 Cost of substrates

In this project is assumed that such price is negligible and the cost of the mass of substrate will be negligible. However, in other circumstances is possible to get a price up to 50 EUR/Mg of substrate is possible since farmers are willing to pay to remove the bio-wastes from their greenhouses. The following formula is presented below:

$$\mathbf{Csubr = M \cdot Cusubr + CT\ [EUR]} \qquad \mathbf{[26]}$$

Where: Csubr – the cost of feedstock [EUR]

M – mass of used substrates [Mg]

Cusubr – the unit price of the substrate [$EUR \cdot Mg^{-1}$]

10.3.2.3 Cost of operation

Operating costs are mainly those incurred to maintain running the system. The main cost of operation is the biomass transport variable from its production center to its collection center or location where the plant will be located. The management of the substrates is also considered an operating cost.

$$\mathbf{Cop = CSM \cdot CT\ [EUR]} \qquad \mathbf{[27]}$$

Where: Cop – the cost of operation [EUR]

CSM – the cost of management [EUR]

CT– the cost of transport of substrate [EUR]

Table 13.- Main operational costs (Consejería de agricultura, pesca y desarrollo rural, 2016).

	Split	Activity	Costs [€/m^2]
Operation costs	Management costs	Removal of greenhouse waste	0,012
	Management costs	Separation of raffia and plastic elements	0,012
	Management costs	Raffias management	0,045
	Management costs	Crushing of plant elements	0,04
	Transport costs	Transport to the plant	0,018

10.3.2.4 Cost of service

Service cost is divided into the cost of maintenance service and technology. In the case of maintenance service, based on data about the cost of repair for machines and installations referred to by different authors (Karwowski 1996, 1998; Grześ, 2002; Muzalewski 2010) and our own data, we can assume that the basket of all service will be annually an average of 3% of the value of the installation. We can assume that the technology cost is 2 EUR/MWh of energy produced (Przyrodniczy et al., 2014). Hence the annual service costs can be approximate based on the following:

$$\mathbf{Cserv = Cms \cdot Cs\ [EUR]} \qquad \mathbf{[28]}$$

Where: Cserv – service cost [EUR]

Cms – maintenance service cost [EUR]

Ctechs – technological service cost [EUR]

$$\mathbf{Cms = Cinst \cdot 0,03\ [EUR]} \qquad \mathbf{[29]}$$

Where: Cms – maintenance service cost [EUR]

Cinst – cost of biogas installation [EUR]

$$\mathbf{Ctechs = Ee \cdot Rtech\ [EUR]} \qquad \mathbf{[30]}$$

Where: Ctechs – technological service cost [EUR]

Ee – amount of electricity produced [MWh]

Rtech – technological cost ratio [EUR · MWh^{-1}]; *we assume 2 EUR/MWh*

10.3.2.5 Cost of staff

The technical personnel cost (maintenance technician, plant operator, process engineer) has been taken into account in technic services. To calculate the cost of the staff is taken the average wage, the number of workers (4), their annual average wage (12.000 euros) and then calculate the approximate cost of personnel on the basis of:

$$\mathbf{Cstaff = Nstaff \cdot Sg\ [EUR]} \qquad \mathbf{[31]}$$

Where: Cstaff – the cost of staff [EUR]

Nstaff – number of employed persons [-]

Sg – average annual gross salary of the employees [EUR]

10.3.2.6 Other costs

Additional expenses related to the administrative work of the plant, insurance, stabilizers, chemical compounds for the measurement of parameters, etc. For this will be considered an annual amount of 5.000 EUR net.

10.3.3 Taxes

A) Value – added tax (VAT – 21%) to balance.
B) Economic activity tax (EAT – 20%) every year. If the net amount of the turnover in the penultimate year is less than 1.000.000 euros it will be exempt, which happens in this particular case.
C) Corporation tax (CT – 20%). If the total income of the entity does not exceed the value of 100.000 euros it will be exempt, which happens in this particular case.

10.3.4 Depreciation

Depreciation is an accounting method in which the decrease in the value of the assets is quantified by their use and deterioration. As it does not constitute a real monetary cost for the company, it should be added once the respective taxes are discounted, because it should be noted that this method grants a decrease in taxes to be paid by the company. The depreciation in this project was assumed to be linear and to 20 years, ergo, at 20 years the assets have a residual value equal to zero:

$$\mathbf{Cdepr = Cinst \cdot 0{,}05\ [EUR]} \qquad \mathbf{[32]}$$

Where: Cdepr – cost of depreciation [EUR]

Cinst – cost of biogas installation [EUR]

10.4 Profitability indicators

In a business project it is very important to analyze the possible profitability of the project and above all whether it is viable or not. Therefore, the following investment indicators have been used: Net Present Value (NPV) and Internal Rate of Return (IRR).

A) Net present value (NPV)

The NPV is defined as the updated value of the expected returns, ergo, the difference between the current value of expected benefits and costs. The projects that maximize the NPV are chosen to make investment decisions. The NPV is calculated from the following equation:

$$\mathbf{NPV = -I + \sum_{n=1}^{N} \frac{CF_n}{(1+IR)^n}} \qquad \mathbf{[33]}$$

Where: NPV – net present value

I – investment cost

N – number of years of plant life

CF_n – net cash flow in year N

IR – interest rate - *in the present case is 0,1*

To establish the interest rate 2 components are in play. The minimum yield required basing on the costs and the investment, which seeks to require reasonable future profits; the risk differential, which seeks to incorporate into the analysis that the uncertainty of the estimated cash flows. Given the volatility of both experimental results and the estimates made in comparison to an implementation on a real scenario, an interest rate of 10% has been chosen.

$$\mathbf{IR = MYR + RD} \qquad \textbf{[34]}$$

Where: IR – interest rate

MYR – minimum yield required

RD – risk differential

B) Internal rate of return (IRR)

The IRR is the interest rate (IR) that a project provides with a NPV of zero, ergo, the profitability that the project is providing. Therefore, the investment in a project is acceptable when the IRR is greater than the expected return on investment.

10.5 Results

The following tables show the annual gross revenues and gross costs of the case study.

Table 14.- Gross revenues of the exploitation

REVENUES	VALUE
FROM ELECTRICITY GENERATION	38.162 €
FROM THERMAL ENERGY GENERATION	20.549 €
FROM DIGESTATE PRODUCTION	110.854 €
FROM CO2 GENERATION	99.749 €
FROM CARBON CREDITS (2018-2022)	4.987 €
FROM CARBON CREDITS (from 2023)	19.950 €
TOTAL GROSS REVENUES	274.301 €

Table 15.- Gross costs of the exploitation.

COSTS	VALUE
MAINTENANCE	69.000 €
TECHNOLOGY SERVICE	1.754 €
OPERATION	30.000 €
STAFF	5.132 €
PROMOTION OF CARBON CREDITS	1.995 €
ELECTRIC TRANSMISSION	0 €
OTHER COSTS	5.000 €
TOTAL GROSS COSTS	112.881 €

It is certain that the benefits might be extraordinary accounting to 161.420 euros annually but this value is tricky. We still have to balance the taxes (VAT) and we have still remember that we have invested 2,3 million of euros on this project that we are expecting to get back.

Thus, we obtain the gross cash flow accounting 134.640 euros and 147.120 euros after balancing the annual VAT tax. See Table 15 to notice how from the fifth year and forward the benefits increase a little bit since, as aforementioned, it is assumed that the price of carbon credits incresases from that moment. That is why there are two values of gross cash flow depending on the year.

Table 16.- Gross cash flow after blancing the annual VAT.

YEAR	GROSS REVENUES [EUR]	VAT (21%)	NET REVENUES [EUR]	GROSS COSTS [EUR]	VAT (21%)	NET COSTS [EUR]	GROSS CASH FLOW [EUR]
1	274.300 €	45.506 €	216.697 €	112.881 €	18.727 €	89.176 €	134.640 €
2	274.300 €	45.506 €	216.697 €	112.881 €	18.727 €	89.176 €	134.640 €
3	274.300 €	45.506 €	216.697 €	112.881 €	18.727 €	89.176 €	134.640 €
4	274.300 €	45.506 €	216.697 €	112.881 €	18.727 €	89.176 €	134.640 €
5	289.263 €	47.989 €	228.518 €	112.881 €	18.727 €	89.176 €	147.120 €
6	289.263 €	47.989 €	228.518 €	112.881 €	18.727 €	89.176 €	147.120 €
7	289.263 €	47.989 €	228.518 €	112.881 €	18.727 €	89.176 €	147.120 €
8	289.263 €	47.989 €	228.518 €	112.881 €	18.727 €	89.176 €	147.120 €
9	289.263 €	47.989 €	228.518 €	112.881 €	18.727 €	89.176 €	147.120 €
10	289.263 €	47.989 €	228.518 €	112.881 €	18.727 €	89.176 €	147.120 €
11	289.263 €	47.989 €	228.518 €	112.881 €	18.727 €	89.176 €	147.120 €
12	289.263 €	47.989 €	228.518 €	112.881 €	18.727 €	89.176 €	147.120 €
13	289.263 €	47.989 €	228.518 €	112.881 €	18.727 €	89.176 €	147.120 €
14	289.263 €	47.989 €	228.518 €	112.881 €	18.727 €	89.176 €	147.120 €
15	289.263 €	47.989 €	228.518 €	112.881 €	18.727 €	89.176 €	147.120 €
16	289.263 €	47.989 €	228.518 €	112.881 €	18.727 €	89.176 €	147.120 €
17	289.263 €	47.989 €	228.518 €	112.881 €	18.727 €	89.176 €	147.120 €
18	289.263 €	47.989 €	228.518 €	112.881 €	18.727 €	89.176 €	147.120 €
19	289.263 €	47.989 €	228.518 €	112.881 €	18.727 €	89.176 €	147.120 €
20	289.263 €	47.989 €	228.518 €	112.881 €	18.727 €	89.176 €	147.120 €

Definetely, those are the real and tangible benefits. Nonetheless, the investment must be recovered and that is why a final cash flow is calculated considering the depreciation that accounts to 115.000 euros annually.

The amortization time of the investment (payback) and the final cash flow as well as other parameters such as the VAN and the IRR that will help us assess the profitability of the case study are shown in the following tables.

Table 17.- Annual total costs during 22 years.

YEAR	NET COSTS [EUR]	DEPRECIATION [EUR]	TOTAL COSTS [EUR]
1	89.176 €	115.000,00 €	204.176 €
2	89.176 €	115.000,00 €	204.176 €
3	89.176 €	115.000,00 €	204.176 €
4	89.176 €	115.000,00 €	204.176 €
5	89.176 €	115.000,00 €	204.176 €
6	89.176 €	115.000,00 €	204.176 €
7	89.176 €	115.000,00 €	204.176 €
8	89.176 €	115.000,00 €	204.176 €
9	89.176 €	115.000,00 €	204.176 €
10	89.176 €	115.000,00 €	204.176 €
11	89.176 €	115.000,00 €	204.176 €
12	89.176 €	115.000,00 €	204.176 €
13	89.176 €	115.000,00 €	204.176 €
14	89.176 €	115.000,00 €	204.176 €
15	89.176 €	115.000,00 €	204.176 €
16	89.176 €	115.000,00 €	204.176 €
17	89.176 €	115.000,00 €	204.176 €
18	89.176 €	115.000,00 €	204.176 €
19	89.176 €	115.000,00 €	204.176 €
20	89.176 €	115.000,00 €	204.176 €
21	89.176 €	0	89.176 €
22	89.176 €	0	89.176 €

Table 18.- Annual amortization and cash flow during 22 years.

YEAR	TOTAL COSTS [EUR]	NET REVENUES [EUR]	CASH FLOW [EUR]	AMORTIZATION [EUR]
1	204.176 €	216.697 €	12.521 €	- 2.185.000,00 €
2	204.176 €	216.697 €	12.521 €	- 2.070.000,00 €
3	204.176 €	216.697 €	12.521 €	- 1.955.000,00 €
4	204.176 €	216.697 €	12.521 €	- 1.840.000,00 €
5	204.176 €	228.518 €	24.341 €	- 1.725.000,00 €
6	204.176 €	228.518 €	24.341 €	- 1.610.000,00 €
7	204.176 €	228.518 €	24.341 €	- 1.495.000,00 €
8	204.176 €	228.518 €	24.341 €	- 1.380.000,00 €
9	204.176 €	228.518 €	24.341 €	- 1.265.000,00 €
10	204.176 €	228.518 €	24.341 €	- 1.150.000,00 €
11	204.176 €	228.518 €	24.341 €	- 1.035.000,00 €
12	204.176 €	228.518 €	24.341 €	- 920.000,00 €
13	204.176 €	228.518 €	24.341 €	- 805.000,00 €
14	204.176 €	228.518 €	24.341 €	- 690.000,00 €
15	204.176 €	228.518 €	24.341 €	- 575.000,00 €
16	204.176 €	228.518 €	24.341 €	- 460.000,00 €
17	204.176 €	228.518 €	24.341 €	- 345.000,00 €
18	204.176 €	228.518 €	24.341 €	- 230.000,00 €
19	204.176 €	228.518 €	24.341 €	- 115.000,00 €
20	204.176 €	228.518 €	24.341 €	- €
21	89.176 €	228.518 €	139.341 €	115.000,00 €
22	89.176 €	228.518 €	139.341 €	230.000,00 €

Table 19.- Summary of indicators in the base case.

INDICATOR	VALUE
NPV	- 1.087.045,47 €
IRR	2,256%
PAYBACK	20 years

INTEREST RATE	0,1

10.6 Discussion and conclusions.

Taking into account the amortization of the installation, the benefits account to 24.341 euros annually, which makes us to think that it is not worth investing at all.

All the same, the negative value of the NPV, which is calculated with the gross cash flow, tell us that the 10 % of interest rate is not accomplished which means that the investment will be producing losses under this minimum profitability required.

An interest rate of 2,26% is obtained and the investment profitability will be the same as placing the funds invested in the market with an equivalent interest rate and the project does not entail any special economic outcome.

For example, when a company is formed and it is necessary to invest a capital, it is expected to obtain a profitability over the years. Therefore, this profitability must be higher than at least an investment with low risk (letters from the State, or deposits in solvent financial institutions). Otherwise it is simpler to invest the money in those products with low risk instead of dedicating time and effort to the business creation.

For those reason the economic evaluation of the case study yields negative results and the project should not be accepted.

The sensitivity analysis that were expected to help us in this evaluation will be not carried out since there is no reason to assess the variables when we get negative results.

11. Conclusions

First of all, due to the large amount of plant remains existing in the Region of Almeria, it can be said that in this region there is a an important biodegradable potential that can be valued. 12,47 GW and 14,96 GW of electric and thermal power respectively can be potentially installed.

On the other hand, the economic evaluation of the case study yields negative results and the project should not be accepted since an investor will always look for projects with higher internal rates of return. The Spanish Energy Reform is contrary to the general interests of Spain and Europe and penalizes, retroactively, those who invested in the development of renewable energy while benefiting dirty technologies. It blocks future investments in renewable energies in Spain from both, native or foreign energy companies and the government must propose clear economic incentives for investors to decide to invest in this type of energy projects in the future.

Furthermore, the viability of the project cannot be assured not only due to the negative results of the economic evaluation but also because of the risks involved in the installation site and the transmission costs (ensuring the sale of thermal energy is very important). Therefore, we cannot ensure that the fermentation process is considered as the most promising alternative technology of vegetable waste processing as long as they are being treated individually.

Nonetheless**,** from a technical point of view, it is feasible to install a complex system of biogas plant connected to greenhouse. It allows using all kinds of produced medias: biogas transformed in electric and thermal energy, digestates as fertilizer and carbon dioxide as vegetable growth accelerator. Besides, unlike the model of composting in piles currently entailing the main treatment of GVW in Almeria, the anaerobic digestion ends its cycle in shorter periods and it is possible to obtain a valuable output faster. The stage corresponding to biodigesters in optimal biochemical and temperature conditions can finish in less than a month, although it can also extend to forty days like in the case study. Unlike this, composting lasts at least three months. However, according to the results, a stratospheric demand of biomass is needed in order to implement a biogas plant of 1 MW electric power. Normally a 500 KW electric power biogas operates with 15.000 tons/year and costs 2 million euros assuring an optimal operation with reduced costs. However, the 107 KW electric power biogas plant in the case of study needs already 17.000 tons/year treatment flow representing a 5 times less efficient installation in terms of energy production, which is a fact reflected in the negative results of the economic evaluation. Therefore, a big biomass must be treated to install a biogas plant with a minimum and reasonable nominal power permitting to obtain a cost-effective installation.

Finally, we can conclude to explain the negative results that the costs associated with the GVW management facility through anaerobic digestion are high and productivity is very low in terms of the energy contained in the biogas compared to the amount of waste treated. However, to emulate the same chemical and physical properties in the samples than the original substrates of the GVW was obviously primordial to perform an appropriate study.

12. Future lines of research

- Conduct a more thorough benchmarking of international and national cases in the production of biogas with the purpose of extracting opportunities and relevant learning for the study and to find out the latest advances.

- Carry out a market study that includes the energy market in order to have a wider vision of the market that allows validating the possible alternatives of the project. Vegetable remains possess a great capacity for biodegradability which makes them potentially very good residues for obtaining biogas as long as they were mixed with substrates with higher biogas potential. For example, there are other elements such as slurry that can be used as a conditioner or even as a constituent for a better mix on anaerobic digestion and they use increasing in recent years. This complementarity of the compositions improves the C/N ratio and increases energy efficiency and therefore the profitability of the facilities through co-digestion. According to AAE (2011) livestock waste and meat and dairy waste are potential substrates for co-digestion in the Almeria region. These co-substrates addition compensates the nutritional deficiencies of GVW and it has several advantages allowing to share treatment facilities, to unify management methodologies - to soften temporal variations in composition and production of each waste separately - and to reduce investment and exploitation costs.

- Study the composition of the digestate in a lab simulation in order to know if it is as valuable as the chemical fertilizer currently being applied in the greenhouses of Almeria and whether it would have enough quality and nutrient content to replace the chemical fertilizer with it.

- The main risks of the project are the installation site and the transmission costs. The viability of the project cannot be assured if there are restrictions by area of influence, so it would be interesting to evaluate its location in depth. Additionally, ensuring the sale of thermal energy is very important so it would be mandatory to ensure an affordable heat transmission installation.

- Finally, different sources of financing might be studied, either for example native companies, government institutions or foreign investors.

Annex A: Subsidies for a biogas plant exploitation.

BOLETÍN OFICIAL DEL ESTADO

Núm. 140 Martes 10 de junio de 2014 Sec. I. Pág. 43876

I. DISPOSICIONES GENERALES

MINISTERIO DE INDUSTRIA, ENERGÍA Y TURISMO

6123 *Real Decreto 413/2014, de 6 de junio, por el que se regula la actividad de producción de energía eléctrica a partir de fuentes de energía renovables, cogeneración y residuos.*

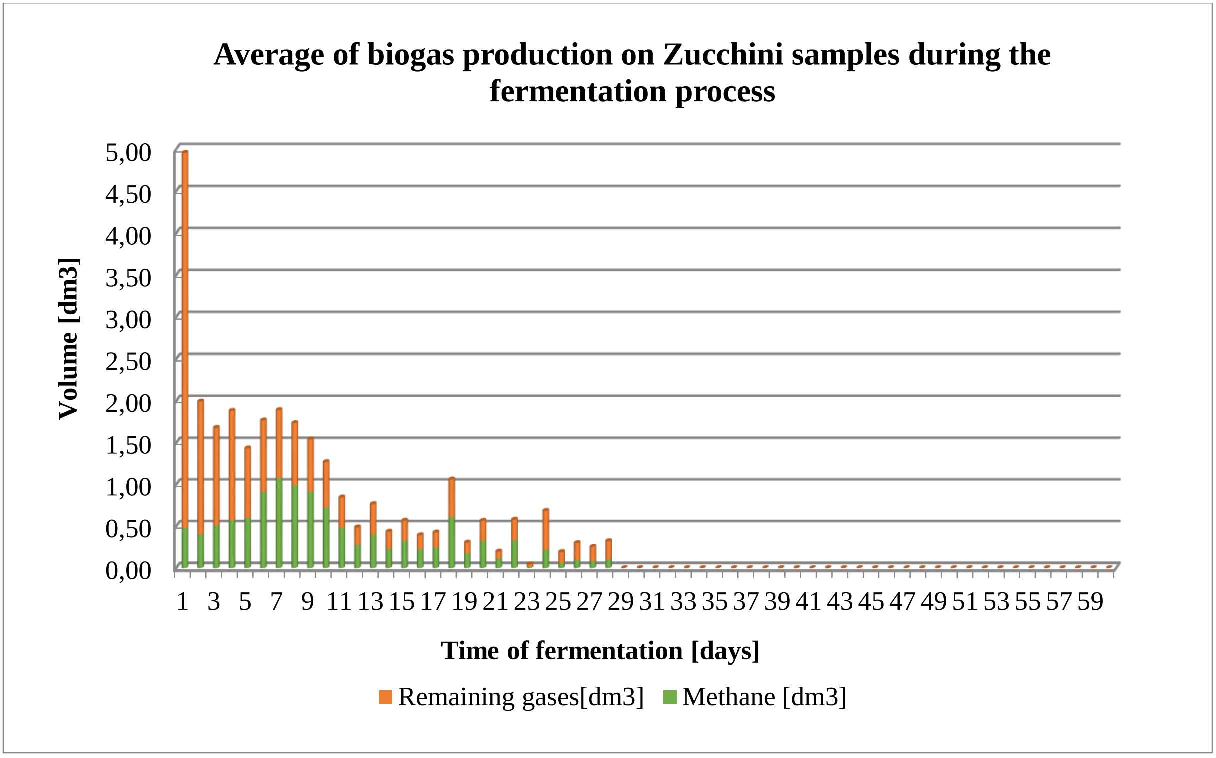
E. Instalaciones tipo aplicables a nuevas instalaciones de producción de energía eléctrica a partir de biomasa situadas en el sistema eléctrico peninsular y para instalaciones de tecnología eólica aprobadas por la Orden IET/2212/2015, de 23 de octubre.

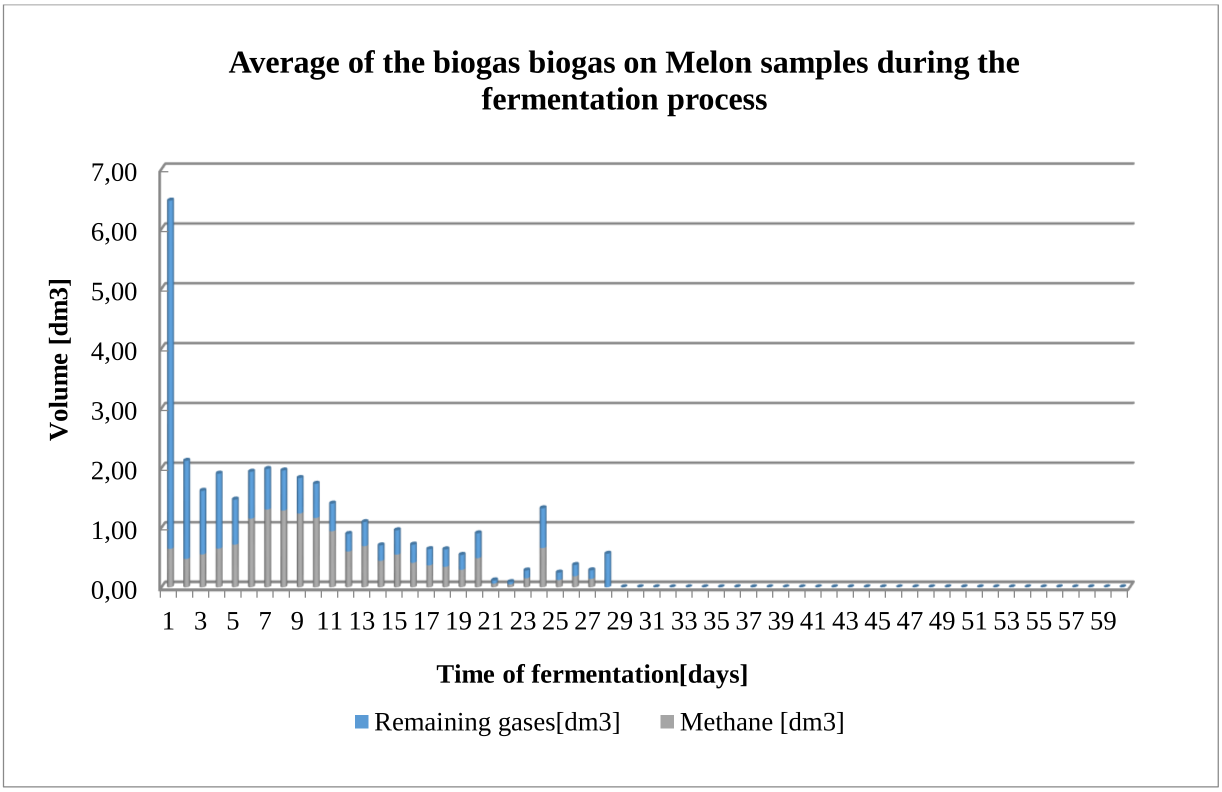
Grupo	Subgrupo	Código de la instalación tipo de referencia	Año de autorización de explotación definitiva	Código instalación tipo
b.6 / b.8	-	ITR-0101	2015	IT-04001
b.6 / b.8	-		2016	IT-04002
b.6 / b.8	-		2017	IT-04003
b.6 / b.8	-		2018	IT-04004
b.6 / b.8	-		2019	IT-04005
b.6 / b.8	-		2020	IT-04006
b.2	-	ITR-0102	2015	IT-04007
b.2	-		2016	IT-04008
b.2	-		2017	IT-04009
b.2	-		2018	IT-04010
b.2	-		2019	IT-04011
b.2	-		2020	IT-04012

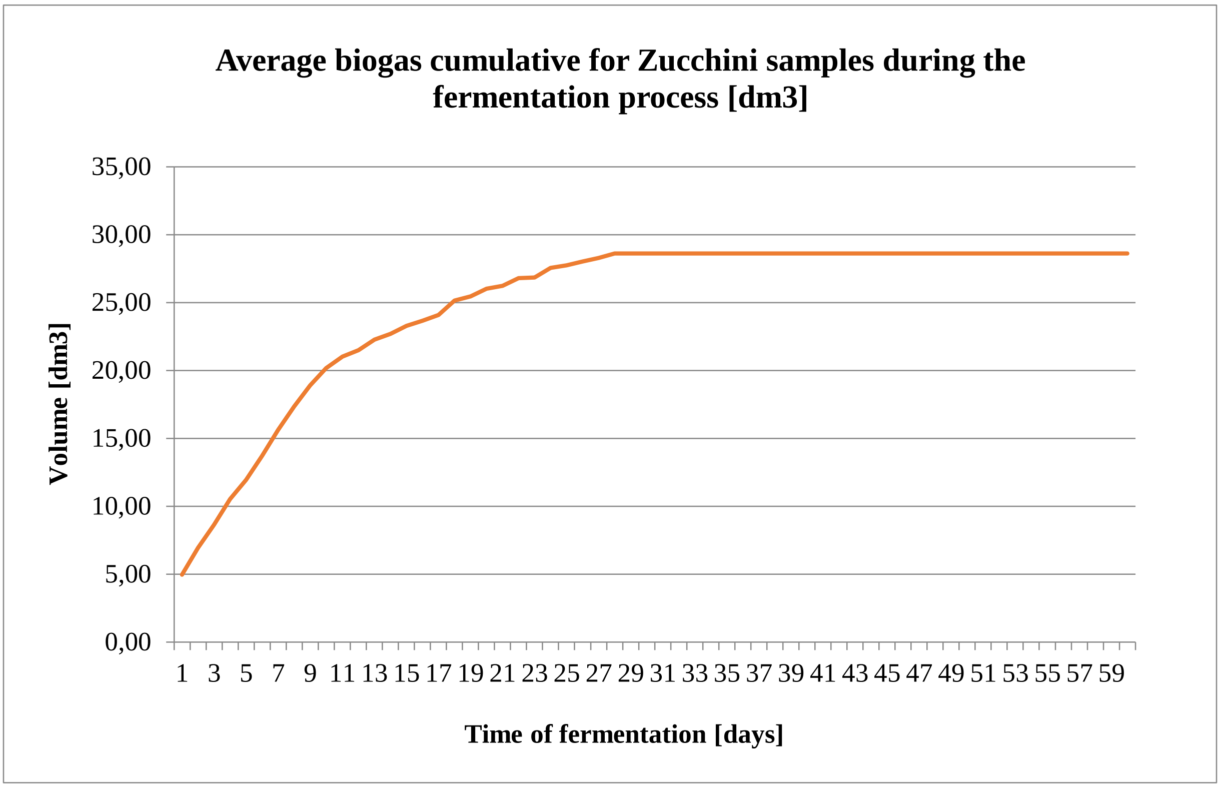
Código de Identificación[1]	Vida Útil Regulatoria (años)[1]	Coeficiente de ajuste $C_{1,a}$	Retribución a la Inversión 2017-2019 Rinv (€/MW)	Nº Horas equivalentes de funcionamiento mínimo anual 2017-2019 Nh (h). [1]	Umbral de funcionamiento anual 2017-2019 Uf (h). [1]	Porcentajes aplicables a Nh y Uf anuales, para el cálculo del nº de horas equivalentes de funcionamiento mínimo y del umbral de funcionamiento de los periodos de 3, 6 y 9 meses(%)		
						3 meses[1]	6 meses[1]	9 meses[1]
IT-03130	20	0,7402	105.307	1.625	975	15%	30%	45%
IT-03131	20	0,7680	105.647	1.500	900	15%	30%	45%
IT-03132	20	0,8249	113.467	1.350	810	15%	30%	45%
IT-03133	20	0,7964	109.557	1.425	855	15%	30%	45%
IT-03134	20	0,7301	100.433	1.600	960	15%	30%	45%
IT-03135	20	0,7049	100.284	1.700	1.020	15%	30%	45%
IT-03136	20	0,5033	71.610	2.250	1.350	15%	30%	45%
IT-03137	20	0,7324	104.194	1.625	975	15%	30%	45%
IT-04001	25	1,0000	3.261	3.000	1.000	18%	37%	55%
IT-04002	25	1,0000	3.209	3.000	1.000	18%	37%	55%
IT-04003	25	0,0000	0	-	-	-	-	-
IT-04004	25	0,0000	0	-	-	-	-	-
IT-04005	25	0,0000	0	-	-	-	-	-
IT-04006	25	-	-	-	-	-	-	-
IT-04007	20	0,0000	0	-	-	-	-	-
IT-04008	20	0,0000	0	-	-	-	-	-
IT-04009	20	0,0000	0	-	-	-	-	-
IT-04010	20	0,0000	0	-	-	-	-	-
IT-04011	20	0,0000	0	-	-	-	-	-
IT-04012	20	-	-	-	-	-	-	-

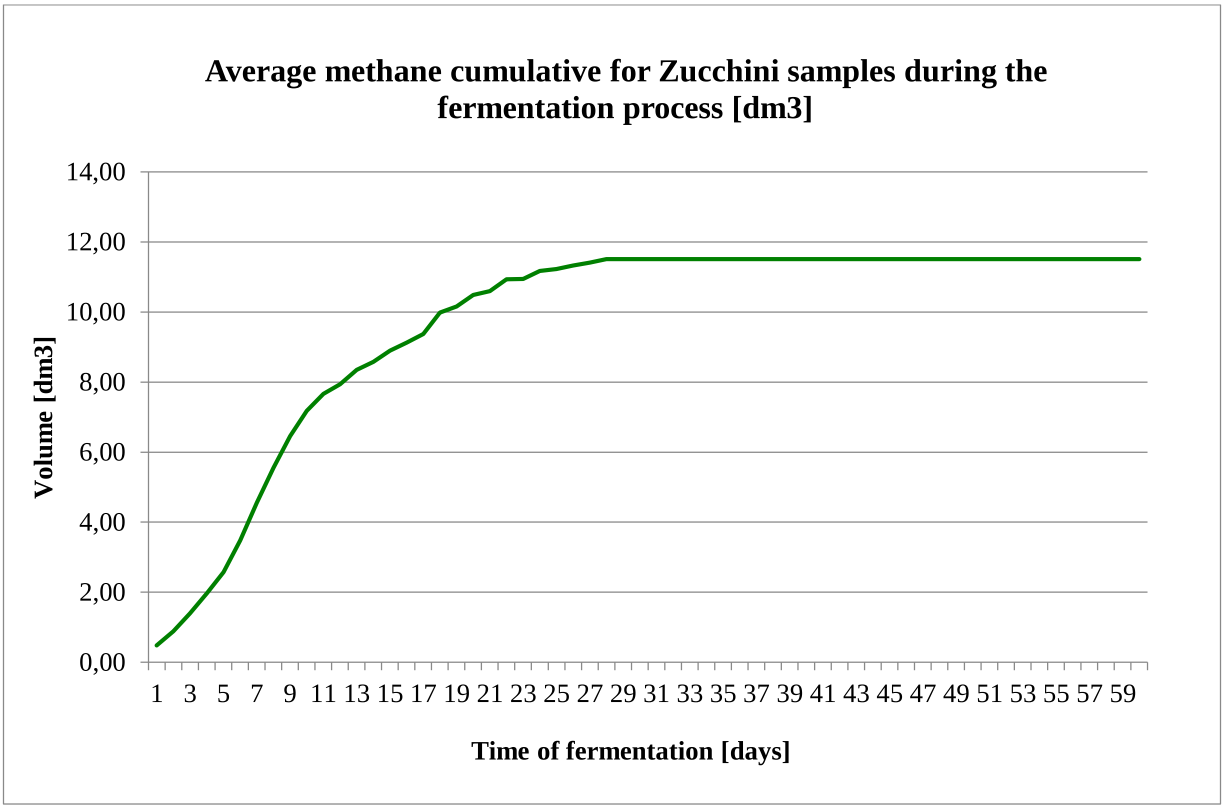
Código de identificación³	Horas de funcionamiento máximo para la percepción de Ro Anual (h)³	Retribución a la Operación Ro (€/MWh) 1° semestre 2017	1° semestre 2017			2° semestre 2017			1° semestre 2018			2° semestre 2018			1° semestre 2019			2° semestre 2019		
			A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
IT-02066	-	0,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IT-02067	-	0,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IT-02068	-	0,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IT-02069	-	0,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IT-02070	-	0,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IT-02071	-	0,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IT-02072	-	0,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IT-02073	-	0,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IT-02074	-	0,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IT-02075	-	0,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IT-02076	-	0,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IT-02077	-	0,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IT-04001	6.500	53,912	4,480	0,011	53,035	4,480	1,000	0,000	4,480	1,000	1,644	4,480	1,000	0,000	4,480	1,000	0,025	4,480	1,000	0,000
IT-04002	6.500	53,921	4,480	0,011	53,044	4,480	1,000	0,000	4,480	1,000	1,644	4,480	1,000	0,000	4,480	1,000	0,025	4,480	1,000	0,000
IT-04003	6.500	53,420	4,480	0,000	53,561	4,480	1,000	0,000	4,480	1,000	1,644	4,480	1,000	0,000	4,480	1,000	0,025	4,480	1,000	0,000
IT-04004	6.500	-	-	-	-	-	-	-	4,480	0,000	55,822	4,480	1,000	0,000	4,480	1,000	0,025	4,480	1,000	0,000
IT-04005	6.500	-	-	-	-	-	-	-	-	-	-	-	-	-	4,480	0,000	58,463	4,480	1,000	0,000
IT-04006	6.500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

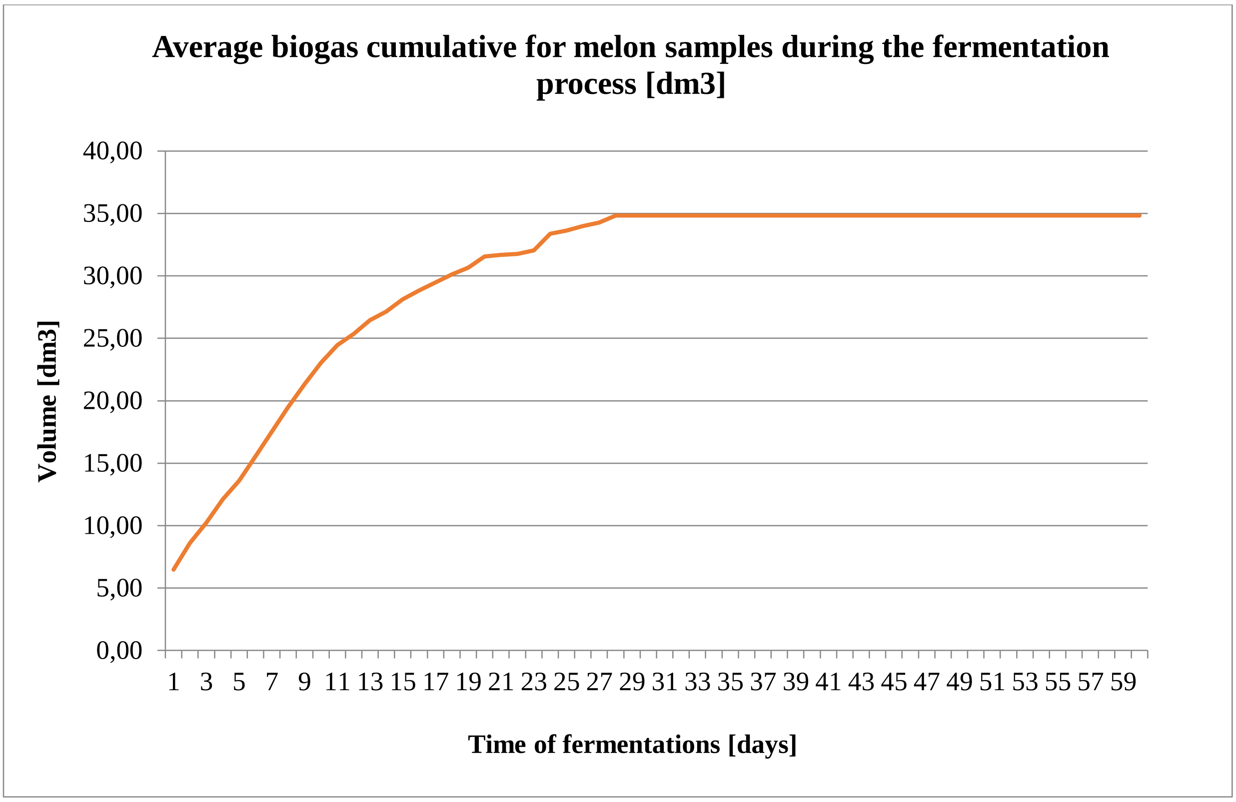
Annex B. Graphics of biogas efficiency tests on VW.



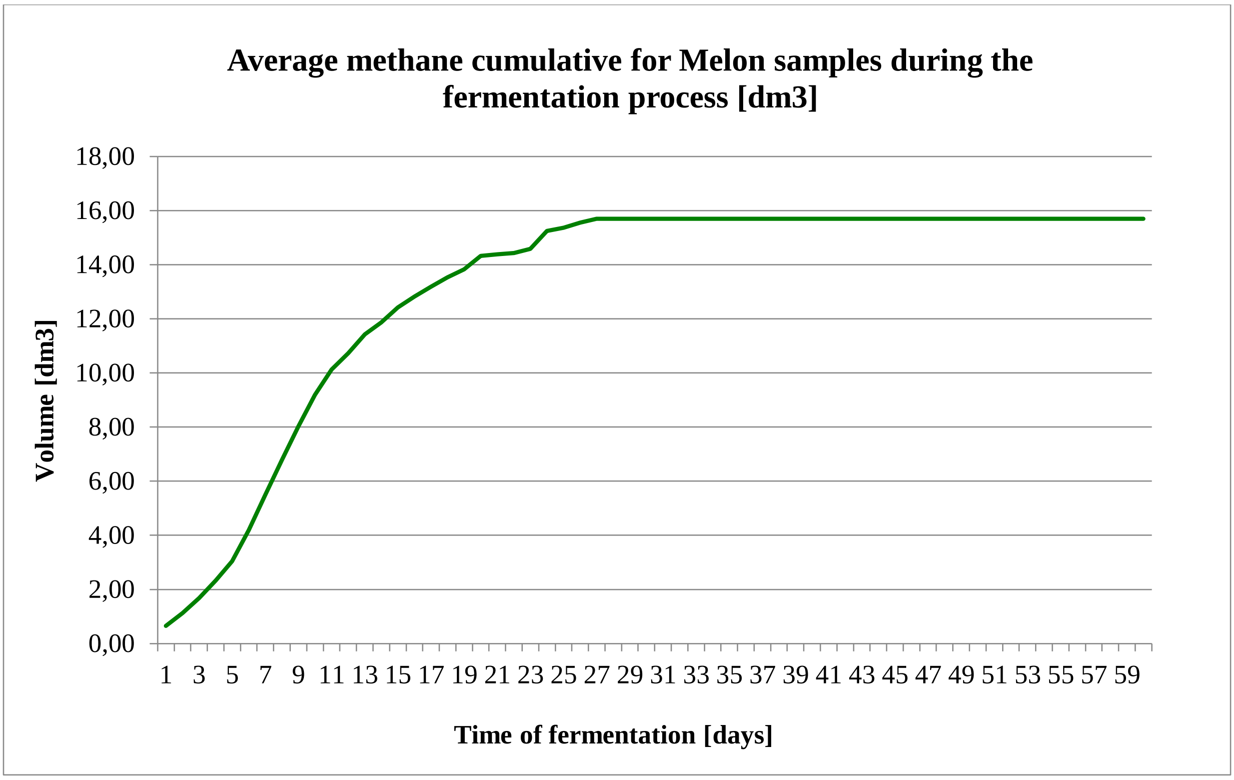



Average biogas cumulative for Zucchini samples during the fermentation process [dm3]
Volume [dm3]
35,00
30,00
25,00
20,00
15,00
10,00
5,00
0,00
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
Time of fermentation [days]


Average methane cumulative for Zucchini samples during the fermentation process [dm3]
Volume [dm3]
14,00
12,00
10,00
8,00
6,00
4,00
2,00
0,00
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
Time of fermentation [days]

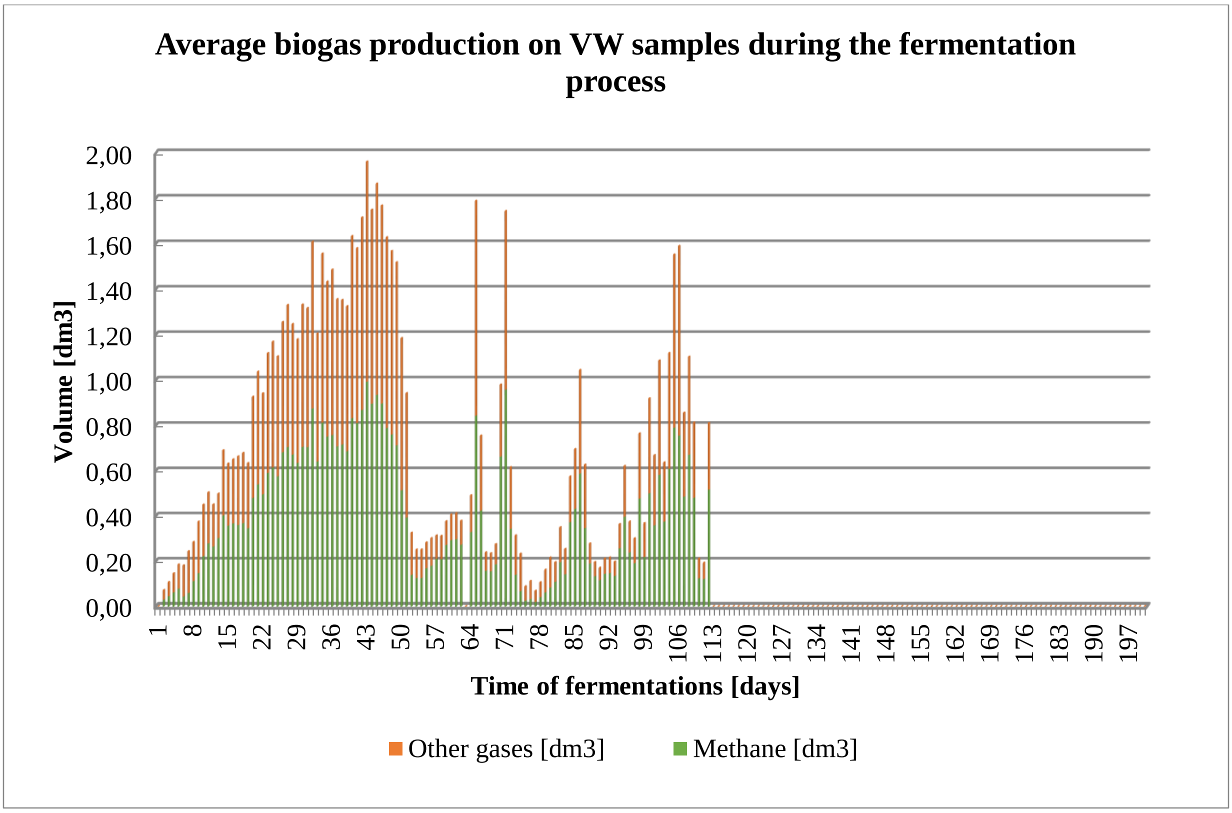


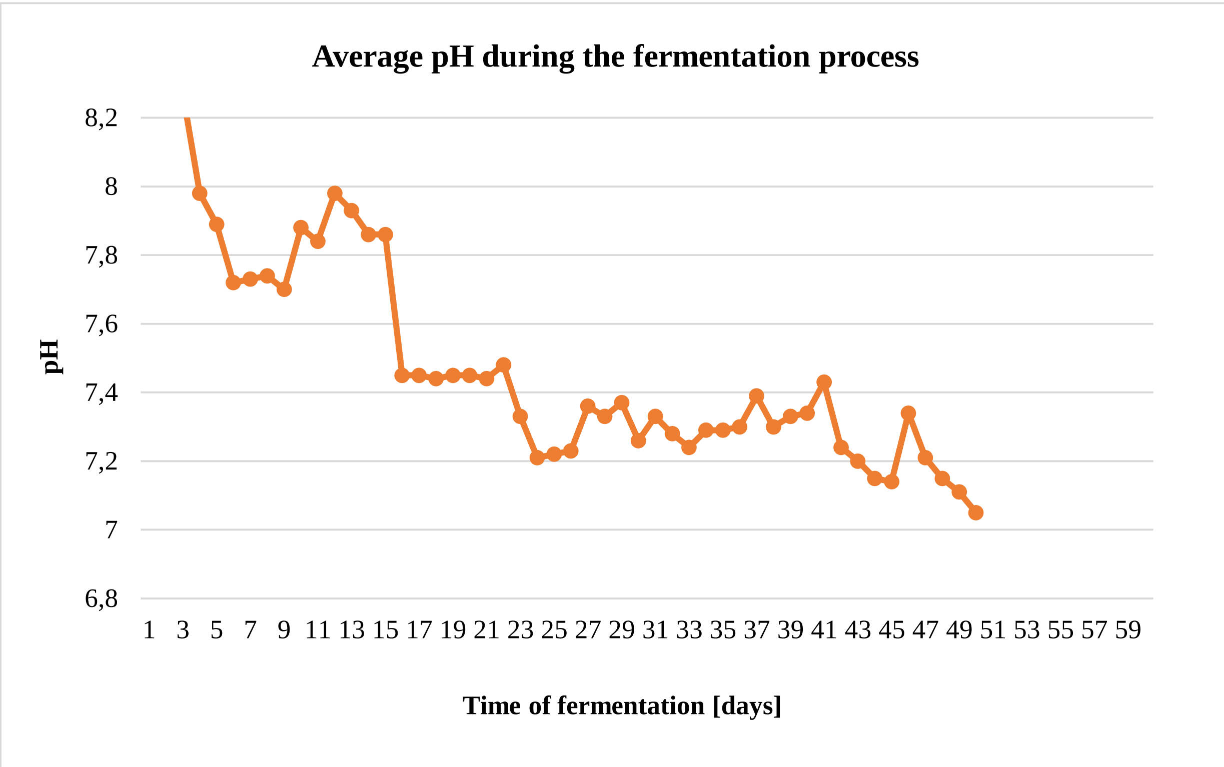
Average biogas cumulative for melon samples during the fermentation process [dm3]
Volume [dm3]
40,00
35,00
30,00
25,00
20,00
15,00
10,00
5,00
0,00
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
Time of fermentations [days]

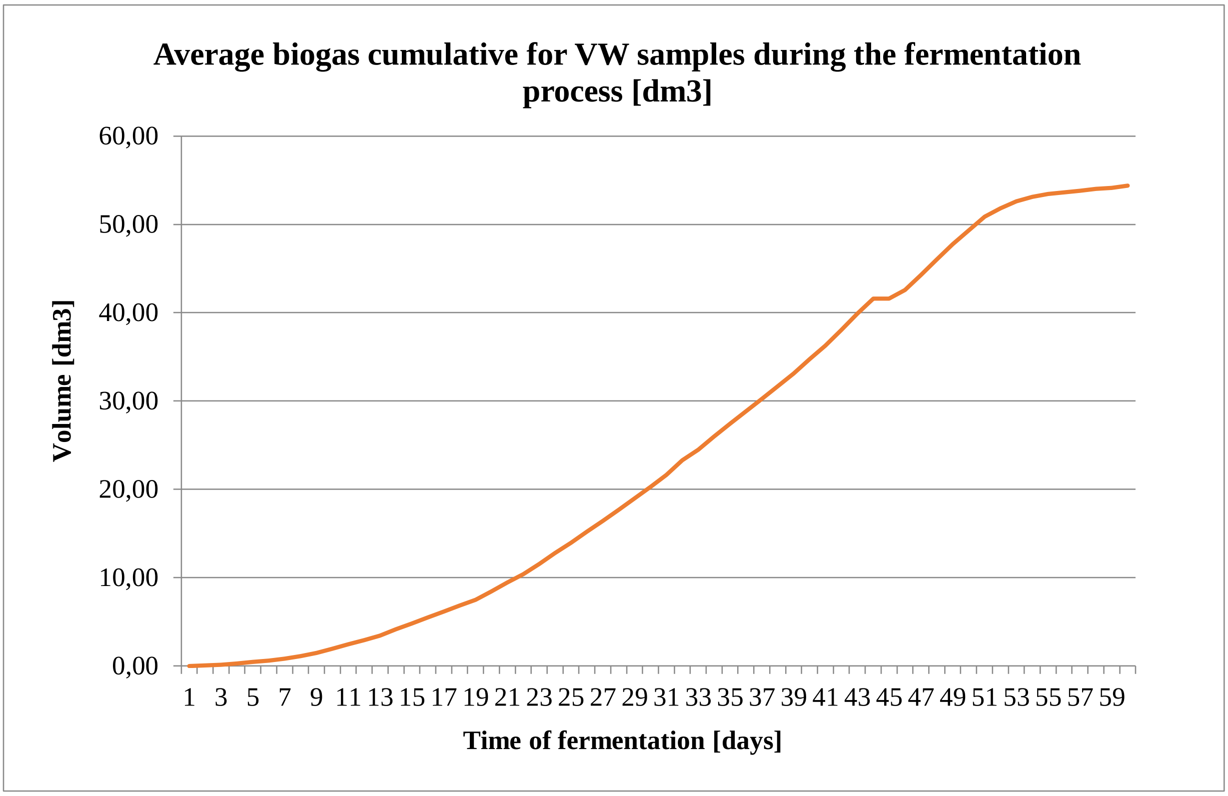


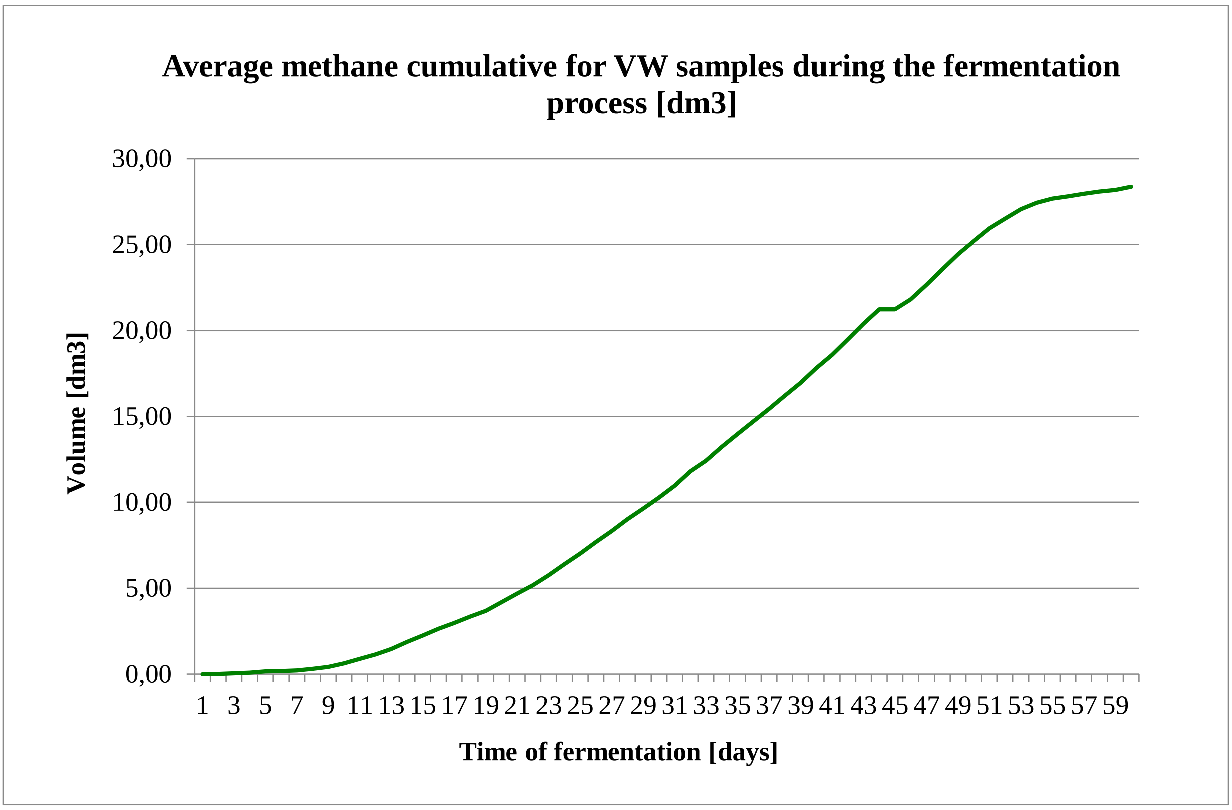
Average methane cumulative for Melon samples during the fermentation process [dm3]
Volume [dm3]
18,00
16,00
14,00
12,00
10,00
8,00
6,00
4,00
2,00
0,00
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
Time of fermentation [days]

Annex C. Graphics of simple continuous fermentation test on VW.






Average biogas cumulative for VW samples during the fermentation process [dm3]
Volume [dm3]
60,00
50,00
40,00
30,00
20,00
10,00
0,00
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
Time of fermentation [days]


Average methane cumulative for VW samples during the fermentation process [dm3]
Volume [dm3]
30,00
25,00
20,00
15,00
10,00
5,00
0,00
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
Time of fermentation [days]

Annex D: Estimation of average methane accumulated for GVW (Table 7).

In function of these percentages estimated, the average methane content of each main vegetable has been calculated in order to estimate the total methane potential of GWV in Almeria. According to Dupuis (2006) the 17 % of total tomato waste are discarded fruits. The other 83 % are leaves and stalks and it varies depending on the type of plant.

Vegetable	Part of the substrate	%	Methane cumulated [m3/Mg f.m.]	Average methane accumulated [m3/Mg f.m]
Tomato	Leaves	0,5	14,61	**14,44**
	Stalks	0,33	12,98	
	Discarded fruits	0,17	16,78	
Pepper	Leaves	0,5	14,00*	**14,19**
	Stalks	0,33	12,00*	
	Discarded fruits	0,17	18,97	
Eggplant	Leaves	0,5	17,38	**16,04**
	Stalks	0,33	12,00*	
	Discarded fruits	0,17	19,96	
Cucumber	Leaves	0,5	17,38	**15,19**
	Stalks	0,33	12,00*	
	Discarded fruits	0,17	14,94	
Greenbean	Leaves	0,6	13,61	**15,69**
	Stalks	0,23	12,00*	
	Discarded fruits	0,17	28,03	
Zucchini	Leaves	0,38	14,00	**12,68**
	Stalks	0,45	12,00*	
	Discarded fruits	0,17	11,51	
Melon	Leaves	0,6	14,00*	**13,83**
	Stalks	0,23	12,00*	
	Discarded fruits	0,17	15,69	
Watermelon	Leaves	0,6	14,00*	**13,59**
	Stalks	0,23	12,00*	
	Discarded fruits	0,17	14,28	

*Some values of methane accumulated on leaves and stalks have been also estimated according to other values of methane accumulated on leaves and stalks that we have been able to test in order to make the calculations the most accurate possible. These values are marked with an asterisk.

Annex E: Dynamic Biogas Technology.

Figure 22 shows an actual biogas plant of this features operating currently in Poland.

a. After initial pre-processing, the input substrates are moved into the initial phase of dynamic decay involving patented specialized bacteria in an innovative separate Biotechnological/Biochemical Processes Accelerator (BPA), which assists in radically reducing of fermentation time. It provides the improvements below:

   - Reduction of fermentation time (40-50% less compared to conventional technologies) as well as the size of the fermentation tanks.
   - Augmentation of the amount of methane from the amount of substrate (15-30% more compared with traditional technologies and depending on the inputs)
   - Post-fermentation solid fraction is minimal.
   - Ability to use a wider variety of substrates in the fermentation process.

b. The methanogenesis process is concluded in stainless steel tanks.

c. The vertically-centralized hydro-pneumatic mixers optimize the conditions for the development of methane bacteria while minimizing the electrical power required for the mixing comparing with traditional technologies.

d. DBT biogas plants are designed to use almost all agricultural products and wastes in fermentation process thanks to the operation of the **BPA system**.

e. The system of input shredding and mixing of the fermenting pulp with biogas (patented) increases the methane content in the biogas by up to 10% compared to the commonly used technologies.

f. The installation is simply to operate and require little specialized training due to a high level of automation.

g. Installation of DBT biogas plants is a fast and efficient process. Pre-fabricated elements are transported directly from factories in Europe to the building site in shipping containers.

h. Construction time will depend on the size of the plant, and will range usually from three to eight weeks.

i. Start-up time with is shortened considerably to a few weeks because of the **heat-resistant steel tanks**.

j. The installations are also removable, and can be disassembled and transported to other locations should the need arise.

k. Due to complete fermentation process, use of the post-fermentation digestate as a fertilizer does not generate any more methane emissions to the atmosphere.

Figure22.- Picture of an actual 1 MWe biogas plant. Fermenters on the left of the image and Biochemical Processes Accelerators (BPAs) on the right (Dynamic biogas Home page, nd).

The objective of the digester employed will be to maximize the amount of biogas produced and the quality of the same for its subsequent use, from the waste treated.

In them a homogeneous distribution is to be maintained in the mixture they contain by their agitation. The arrangement of propellers or blades inside the reactor, either on its horizontal or vertical axis, will generate a stirring of the mixture that will achieve a homogenization of the waste and microorganisms of the process. This avoids the appearance of decantation problems and the like, which would deplete the biogas production capacity.

In addition, between these two types of digesters, the most advisable for agricultural waste would be a reactor without recirculation, since one with recirculation would only apply to wastewater with a high organic load content (wastewater from sugar mills, breweries, etc., so that a liquid-solid phase separation is possible (Estudio básico del biogás, 2011). Therefore, the digester would have its corresponding agitation system and biogas and effluent extraction systems.

There are other types of full mix reactors, such as piston flow and discontinuous digester. The first presents problems of vertical homogeneity, and the second presents an efficiency of the scarce process since there are dead times between one phase and another, and the absence of mixing systems slows down the complete anaerobic digestion of the introduced substrates (Tolón Becerra & Lastra Bravo, 2010).

Main components of an anaerobic digester:

In order for the digester to be built efficiently and no problems arise during the operation (biogas leaks, filtration of substrates, etc.), a suitable design must be made, depending on the waste to be treated and the performance to be achieved

The following are the most important parts that will serve as the basis for the subsequent sizing of the digester for agricultural residues:

- Digester tanks are built on land.
- The floor and walls will be stainless steel
- The cover will be rigid, so a gas meter will be needed to store the biogas
- The cover of the storage of digestate will be membrane, so it will also store biogas and biogas will be used, which is still produced post-fermentation (even if little) from the digestate. This same cover will act as a gasometer.
- The feed of the digesters will be carried out by means of a conveyor belt that introduces the residues by the part superior of the digester.
- The discharge of the already digested mixture or the recirculation of the same to stabilize the humidity levels of the process, is done by means of overflow. To do this, a pipe is installed in the top part of the digester that will connect this to the digestate storage tank and / or the recirculation tank.
- Through agitation a better distribution of temperature, nutrients, removal of biogas bubbles and a mixture of the fresh substrate with the bacterial population in the digester is achieved. In addition, the formation of crusts on the surface of the biomass and the formation of "dead spaces" without biological activity is avoided.
- The digesters will incorporate a polyurethane insulation system (or similar) to retain as much heat as possible. A series of polyethylene tubes that will make up the heating system will also be distributed inside the steel wall. The hot water circulating inside the heating system will come from the water of the thermal energy obtained in the cogeneration engine.

Annex F: Cash flow of the economic evaluation.

	2018	2019	2020	2021	2022
	Year 0	Year 1	Year 2	Year 3	Year 4
GROSS REVENUES		274.300,35 €	274.300,35 €	274.300,35 €	274.300,35 €
NET REVENUES		216.697,28 €	216.697,28 €	216.697,28 €	216.697,28 €
Electric energy		38.161,79 €	38.161,79 €	38.161,79 €	38.161,79 €
Thermal energy		20.548,65 €	20.548,65 €	20.548,65 €	20.548,65 €
Biofertilizers		110.853,75 €	110.853,75 €	110.853,75 €	110.853,75 €
CO2 recovery		99.748,73 €	99.748,73 €	99.748,73 €	99.748,73 €
Carbon credits		4.987,44 €	4.987,44 €	4.987,44 €	4.987,44 €
VAT debit (21%)		45.506,43 €	45.506,43 €	45.506,43 €	45.506,43 €
GROSS COSTS		112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €
NET COSTS		89.176,03 €	112.881,05 €	112.881,05 €	112.881,05 €
Cost of maintainance service		69.000,00 €	69.000,00 €	69.000,00 €	69.000,00 €
Cost of technology service		1.753,60 €	1.753,60 €	1.753,60 €	1.753,60 €
Cost of electric transmission		- €	- €	- €	- €
Cost of carbon credits		1.994,97 €	1.994,97 €	1.994,97 €	1.994,97 €
Cost of operation		30.000,00 €	30.000,00 €	30.000,00 €	30.000,00 €
Cost of staff		5.132,48 €	5.132,48 €	5.132,48 €	5.132,48 €
Other costs		5.000,00 €	5.000,00 €	5.000,00 €	5.000,00 €
VAT credit (21%)		18.726,97 €	18.726,97 €	18.726,97 €	18.726,97 €
NET VAT (21%)		26.779,46 €	26.779,46 €	26.779,46 €	26.779,46 €
VAT Annual Payment		26.779,46 €	26.779,46 €	26.779,46 €	26.779,46 €
GROSS CASH FLOW		134.639,84 €	134.639,84 €	134.639,84 €	134.639,84 €
INVESMENT	2.300.000,00 €				
Depreciation		115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €
		115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €
AMORTIZATION		- 2.185.000,00 €	- 2.070.000,00 €	- 1.955.000,00 €	- 1.840.000,00 €
GROSS PROFIT (before taxes)		19.639,84 €	19.639,84 €	19.639,84 €	19.639,84 €
Personal Income Tax (20%)	exempt				
Income tax to pay	exempt	26.927,97 €	26.927,97 €	26.927,97 €	26.927,97 €
NET PROFIT (after taxes)		19.639,84 €	19.639,84 €	19.639,84 €	19.639,84 €
Working capital	0	0	0	0	0
NET CASH FLOW					
Net cash flow of the period	- 2.300.000,00 €	**134.639,84 €**	**134.639,84 €**	**134.639,84 €**	**134.639,84 €**
Net cash flow cumulated		134.639,84 €	269.279,68 €	403.919,51 €	538.559,35 €

2023	2024	2025	2026	2027	2028	2029
Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11
289.262,66 €	289.262,66 €	289.262,66 €	289.262,66 €	289.262,66 €	289.262,66 €	289.262,66 €
228.517,50 €	228.517,50 €	228.517,50 €	228.517,50 €	228.517,50 €	228.517,50 €	228.517,50 €
38.161,79 €	38.161,79 €	38.161,79 €	38.161,79 €	38.161,79 €	38.161,79 €	38.161,79 €
20.548,65 €	20.548,65 €	20.548,65 €	20.548,65 €	20.548,65 €	20.548,65 €	20.548,65 €
110.853,75 €	110.853,75 €	110.853,75 €	110.853,75 €	110.853,75 €	110.853,75 €	110.853,75 €
99.748,73 €	99.748,73 €	99.748,73 €	99.748,73 €	99.748,73 €	99.748,73 €	99.748,73 €
19.949,75 €	19.949,75 €	19.949,75 €	19.949,75 €	19.949,75 €	19.949,75 €	19.949,75 €
47.988,68 €	47.988,68 €	47.988,68 €	47.988,68 €	47.988,68 €	47.988,68 €	47.988,68 €
112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €
112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €
69.000,00 €	69.000,00 €	69.000,00 €	69.000,00 €	69.000,00 €	69.000,00 €	69.000,00 €
1.753,60 €	1.753,60 €	1.753,60 €	1.753,60 €	1.753,60 €	1.753,60 €	1.753,60 €
- €	- €	- €	- €	- €	- €	- €
1.994,97 €	1.994,97 €	1.994,97 €	1.994,97 €	1.994,97 €	1.994,97 €	1.994,97 €
30.000,00 €	30.000,00 €	30.000,00 €	30.000,00 €	30.000,00 €	30.000,00 €	30.000,00 €
5.132,48 €	5.132,48 €	5.132,48 €	5.132,48 €	5.132,48 €	5.132,48 €	5.132,48 €
5.000,00 €	5.000,00 €	5.000,00 €	5.000,00 €	5.000,00 €	5.000,00 €	5.000,00 €
18.726,97 €	18.726,97 €	18.726,97 €	18.726,97 €	18.726,97 €	18.726,97 €	18.726,97 €
29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €
29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €
147.119,90 €	147.119,90 €	147.119,90 €	147.119,90 €	147.119,90 €	147.119,90 €	147.119,90 €
115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €
115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €
- 1.725.000,00 €	- 1.610.000,00 €	- 1.495.000,00 €	- 1.380.000,00 €	- 1.265.000,00 €	- 1.150.000,00 €	- 1.035.000,00 €
32.119,90 €	32.119,90 €	32.119,90 €	32.119,90 €	32.119,90 €	32.119,90 €	32.119,90 €
29.423,98 €	29.423,98 €	29.423,98 €	29.423,98 €	29.423,98 €	29.423,98 €	29.423,98 €
32.119,90 €	32.119,90 €	32.119,90 €	32.119,90 €	32.119,90 €	32.119,90 €	32.119,90 €
0	0	0	0	0	0	0
147.119,90 €	**147.119,90 €**	**147.119,90 €**	**147.119,90 €**	**147.119,90 €**	**147.119,90 €**	**147.119,90 €**
685.679,25 €	832.799,15 €	979.919,05 €	1.127.038,95 €	1.274.158,85 €	1.421.278,75 €	1.568.398,65 €

2030	2031	2032	2033	2034	2035	2036
Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18
289.262,66 €	289.262,66 €	289.262,66 €	289.262,66 €	289.262,66 €	289.262,66 €	289.262,66 €
228.517,50 €	228.517,50 €	228.517,50 €	228.517,50 €	228.517,50 €	228.517,50 €	228.517,50 €
38.161,79 €	38.161,79 €	38.161,79 €	38.161,79 €	38.161,79 €	38.161,79 €	38.161,79 €
20.548,65 €	20.548,65 €	20.548,65 €	20.548,65 €	20.548,65 €	20.548,65 €	20.548,65 €
110.853,75 €	110.853,75 €	110.853,75 €	110.853,75 €	110.853,75 €	110.853,75 €	110.853,75 €
99.748,73 €	99.748,73 €	99.748,73 €	99.748,73 €	99.748,73 €	99.748,73 €	99.748,73 €
19.949,75 €	19.949,75 €	19.949,75 €	19.949,75 €	19.949,75 €	19.949,75 €	19.949,75 €
47.988,68 €	47.988,68 €	47.988,68 €	47.988,68 €	47.988,68 €	47.988,68 €	47.988,68 €
112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €
112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €
69.000,00 €	69.000,00 €	69.000,00 €	69.000,00 €	69.000,00 €	69.000,00 €	69.000,00 €
1.753,60 €	1.753,60 €	1.753,60 €	1.753,60 €	1.753,60 €	1.753,60 €	1.753,60 €
- €	- €	- €	- €	- €	- €	- €
1.994,97 €	1.994,97 €	1.994,97 €	1.994,97 €	1.994,97 €	1.994,97 €	1.994,97 €
30.000,00 €	30.000,00 €	30.000,00 €	30.000,00 €	30.000,00 €	30.000,00 €	30.000,00 €
5.132,48 €	5.132,48 €	5.132,48 €	5.132,48 €	5.132,48 €	5.132,48 €	5.132,48 €
5.000,00 €	5.000,00 €	5.000,00 €	5.000,00 €	5.000,00 €	5.000,00 €	5.000,00 €
18.726,97 €	18.726,97 €	18.726,97 €	18.726,97 €	18.726,97 €	18.726,97 €	18.726,97 €
29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €
29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €
147.119,90 €	147.119,90 €	147.119,90 €	147.119,90 €	147.119,90 €	147.119,90 €	147.119,90 €
115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €
115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €
- 920.000,00 €	- 805.000,00 €	- 690.000,00 €	- 575.000,00 €	- 460.000,00 €	- 345.000,00 €	- 230.000,00 €
32.119,90 €	32.119,90 €	32.119,90 €	32.119,90 €	32.119,90 €	32.119,90 €	32.119,90 €
29.423,98 €	29.423,98 €	29.423,98 €	29.423,98 €	29.423,98 €	29.423,98 €	29.423,98 €
32.119,90 €	32.119,90 €	32.119,90 €	32.119,90 €	32.119,90 €	32.119,90 €	32.119,90 €
0	0	0	0	0	0	0
147.119,90 €	**147.119,90 €**	**147.119,90 €**	**147.119,90 €**	**147.119,90 €**	**147.119,90 €**	**147.119,90 €**
1.715.518,55 €	1.862.638,45 €	2.009.758,35 €	2.156.878,25 €	2.303.998,15 €	2.451.118,05 €	2.598.237,95 €

2037	2038	2039	2040	2041	2042
Year 19	Year 20	Year 21	Year 22	Year 23	Year 24
289.262,66 €	289.262,66 €	289.262,66 €	289.262,66 €	289.262,66 €	289.262,66 €
228.517,50 €	228.517,50 €	228.517,50 €	228.517,50 €	228.517,50 €	228.517,50 €
38.161,79 €	38.161,79 €	38.161,79 €	38.161,79 €	38.161,79 €	38.161,79 €
20.548,65 €	20.548,65 €	20.548,65 €	20.548,65 €	20.548,65 €	20.548,65 €
110.853,75 €	110.853,75 €	110.853,75 €	110.853,75 €	110.853,75 €	110.853,75 €
99.748,73 €	99.748,73 €	99.748,73 €	99.748,73 €	99.748,73 €	99.748,73 €
19.949,75 €	19.949,75 €	19.949,75 €	19.949,75 €	19.949,75 €	19.949,75 €
47.988,68 €	47.988,68 €	47.988,68 €	47.988,68 €	47.988,68 €	47.988,68 €
112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €
112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €	112.881,05 €
69.000,00 €	69.000,00 €	69.000,00 €	69.000,00 €	69.000,00 €	69.000,00 €
1.753,60 €	1.753,60 €	1.753,60 €	1.753,60 €	1.753,60 €	1.753,60 €
- €	- €	- €	- €	- €	- €
1.994,97 €	1.994,97 €	1.994,97 €	1.994,97 €	1.994,97 €	1.994,97 €
30.000,00 €	30.000,00 €	30.000,00 €	30.000,00 €	30.000,00 €	30.000,00 €
5.132,48 €	5.132,48 €	5.132,48 €	5.132,48 €	5.132,48 €	5.132,48 €
5.000,00 €	5.000,00 €	5.000,00 €	5.000,00 €	5.000,00 €	5.000,00 €
18.726,97 €	18.726,97 €	18.726,97 €	18.726,97 €	18.726,97 €	18.726,97 €
29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €
29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €	29.261,71 €
147.119,90 €	147.119,90 €	147.119,90 €	147.119,90 €	147.119,90 €	147.119,90 €
115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €	115.000,00 €
115.000,00 €	115.000,00 €				
- 115.000,00 €	- €	115.000,00 €	230.000,00 €	345.000,00 €	460.000,00 €
32.119,90 €	32.119,90 €	147.119,90 €	147.119,90 €	147.119,90 €	147.119,90 €
29.423,98 €	29.423,98 €	29.423,98 €	29.423,98 €	29.423,98 €	29.423,98 €
32.119,90 €	32.119,90 €	147.119,90 €	147.119,90 €	147.119,90 €	147.119,90 €
0	0	0	0	0	0
147.119,90 €	**147.119,90 €**	**147.119,90 €**	**147.119,90 €**	**147.119,90 €**	**147.119,90 €**
2.745.357,85 €	2.892.477,75 €	3.039.597,65 €	3.186.717,55 €	3.333.837,45 €	3.480.957,35 €

Annex G. Fertilizer cost estimation.

Annual incomes for the farmers	7,01	eur/m^2·year
Annual costs for the farmers	4,12	eur/m^2·year
Annual benefits for the farmers	2,89	eur/m^2·year
% of cost that entails the cost of fertilizers	7	%
Total area of greenhouses	29.000	ha
Use of fertilizers	2.000	Kg/ha·year
Total annual fertilizer cost	836.360	eur/year
Total annual use of fertilizers	58.000	Mg/year
Fertilizer cost	14,42	eur/Mg

$$Total\ annual\ fertilizer\ cost = \ 4{,}12\frac{eur}{m^2 \cdot year} \cdot \frac{100\ m^2}{1\ ha} \cdot 0{,}07 \cdot 2900\ ha = 836360\frac{eur}{year}$$

$$Total\ annual\ use\ of\ fertilizers = 2000\frac{Kg}{ha \cdot year} \cdot 2900\ ha \cdot \frac{1\ Mg}{1000\ Kg} = 58000\frac{Mg}{year}$$

$$\boldsymbol{Fertilizer\ cost} = \frac{836360\frac{eur}{year}}{58000\frac{Mg}{year}} = \boldsymbol{14,42\frac{eur}{Mg}}$$

Annex H: Tolls to access to the transport and distribution grids.

BOLETÍN OFICIAL DEL ESTADO

Núm. 314 | Jueves 29 de diciembre de 2016 | Sec. I. Pág. 91089

I. DISPOSICIONES GENERALES

MINISTERIO DE ENERGÍA, TURISMO Y AGENDA DIGITAL

12464 *Orden ETU/1976/2016, de 23 de diciembre, por la que se establecen los peajes de acceso de energía eléctrica para 2017.*

2. A partir de la entrada en vigor de la presente orden, los productores de energía eléctrica que actúen en el ámbito del Mercado Ibérico de la Electricidad pagarán al Operador del Mercado, por cada una de las instalaciones de potencia neta o instalada, en el caso renovables, cogeneración o residuos, con régimen retributivo primado o específico, superior a 1 MW, una cantidad mensual fija de 8,73 euros/MW de potencia disponible.

Para el cálculo de la potencia disponible se aplicará a la potencia neta o instalada en el caso tecnologías renovables, cogeneración y residuos con régimen retributivo primado o específico, de cada instalación, el valor del coeficiente de disponibilidad aplicable al régimen y tecnología que le corresponda, de acuerdo con lo establecido en el siguiente cuadro:

	% disponibilidad
Tecnología:	
Nuclear	87
Hulla+antracita	90
Lignito negro	89
Carbón de importación	94
Fuel-gas	75
Ciclo combinado	93
Bombeo	73
Hidráulica convencional	59
Instalaciones con régimen retributivo específico:	
Hidráulica	29
Biomasa	45
Eólica	22
R.S. Industriales	52
R.S. Urbanos	48
Solar	11
Calor Residual	29
Carbón	90
Fuel-Gasoil	26
Gas de Refinería	22
Gas Natural	39

14. References

Agencia Andaluza de la Energía [AAE] (2011). *Estudio básico del biogás*. Consejería de empleo, empresa y comercio, Junta de Andalucía. Available at: https://www.agenciaandaluzadelaenergia.es/sites/default/files/documentos/estudio_basico_del_biogas_0.pdf [Accessed 24 Dec. 2016], 1-155.

Agencia Andaluza de la Energia [AAE] (2015). *Informe de Infraestructuras energéticas Provincia Jaén*. Consejería de empleo, empresa y comercio, Junta de Andalucía. Available at: https://www.agenciaandaluzadelaenergia.es/sites/default/files/documentos/informe_prov_almeria_miea.pdf [Accesed 24 Dec. 2016], 1-24.

Agència de Residus de Catalunya [ARC] (2017). *Digestión anaerobia*. [online] Available at: http://residus.gencat.cat/es/ambits_dactuacio/valoritzacio_reciclatge/instal_lacions_de_gestio/tractament_biologic/digestio_anaerobia/ [Accessed 15 May 2017].

Barth, C., Powers, T. (2008). *Agricultural waste characteristics*. Agricultural waste management field handbook. United States Department of Agriculture. South Carolina, 1-32.

Bouallagui, H., Lahdheb, H., Romdan, E., Rachdi, B. & Hamdi., M. (2009). *Improvement of fruit and vegetable waste anaerobic digestion performance and stability with co-substrates addition.* J. Environ*, 90(5), 1844-1849.

Cabrera, A., Uclés, D., Agüera, T. (2015). *Análisis de la campaña hortofrutícola de Almería. Campaña 2014/2015.* Servicio de Estudios de Cajamar. Informes y Monografías / 51. Available at: http://www.publicacionescajamar.es/pdf/series-tematicas/informes-coyuntura-analisis-de-campana/analisis-de-la-campana-hortofruticola-15.pdf [Accessed 23 Dec. 2016], 1-82.

Cepero, L., et al. (2012). *Producción de biogás y bioabonos a partir de efluentes de biodigestores*. Pastos y Forrajes, 35(2), 219-226.

Cieślik, M., Dach, J., Lewicki, A., Smurzyńska, A., Janczak, D., Pawlicka-Kaczorowska, J. & Jóźwiakowski, K. (2016). *Methane fermentation of the maize straw silage under meso- and thermophilic conditions.* Energy, 115(2), 1495-1502.

Consejería de agricultura, pesca y desarrollo rural (2016). *Estrategia de gestión de restos vegetales en la horticultura de Andalucía hacia una economía circular*. Junta de Andalucía Available at: http://www.juntadeandalucia.es/export/drupaljda/Estrategia_gestion_restos_vegetales_hor ticultura_Andalucia_BORRADOR_V12.pdf [Accessed 24. Dec. 2016], 1-40.

Cubero Madriz, G. A. (2011). *Evaluación de un sistema de digestión anaerobia para la estabilización de lodos provenientes de las aguas residuales*. Ingeniería ambiental. Instituto Tecnológico de Costa Rica, 1-131.

Deloitte (2015). *European energy market reform Country profile: Spain*. Energy market reform in Europe. European energy and climate policies: achievements and challenges to 2020 and beyond, 119-134.

Dudek, J. & Zaleska-Bartosz, J. (2010). *Production and use of biogas for energy purposes*. Problems of Ecology, 14(1).

Dupuis, I. (2006). *Estimación de los residuos agrícolas generados en la isla de Tenerife.* Servicio técnico de agricultura y desarrollo rural. Available at: http://www.agrocabildo.org/publicaciones_detalle.asp?id=28 [Accessed 8 Feb. 2017].1-20.

Dynamic biogas Home page (nd). [Figure]. Dynamic Biogas®. Poland. [online] Available at: http://dynamicbiogas.com/ [Accessed 21 Feb. 2017].

Edwiges, T., Frare, L., Mayer, B., Lins, L., Mi Triolo, J., Flotats, X., & de Mendonça Costa, M. S. S. (2017). *Influence of chemical composition on biochemical methane potential of fruit and vegetable waste*. Waste Management. [online] Available at: www.elsevier.com/locate/wasman [Accessed 25 Jan. 2018]

Esen, M. & Yuksel, T. (2013). *Experimental evaluation of using various renewable energy sources for heating a greenhouse.* Energy and Buildings, 65, 340-351.

Francisco, M. A. (2007). *Gasificación de residuos de invernadero para la obtención de energía eléctrica en el sur de España*: *ubicación mediante sig,* 32(2), 131-136.

Grala, A., Zieliński, M., Dębowski, M., & Dudek, M. (2012). *Effects of Hydrothermal Depolymerization and Enzymatic Hydrolysis of Algae Biomass on Yield of Methane Fermentation Process,* 21(2), 363-368.

Grześ, Z. (2002). *Badania rzeczywistych kosztów obsługi technicznej nowoczesnych kombajnów zbożowych*. Rocz. AR Pozn. CCCXLIII, Ekon, 1, 123-127.

Hills, D.J. & Nakano, L. (1984). *Effects of particle size on anaerobic digestion of tomato solid waste*. Agric Wastes, 10(4), 285-295.

IDAE (2007). *Biomasa: Digestores anaerobios*. Instituto para la Diversificación y Ahorro de la Energía (IDAE). Ministerio de industria, turismo y comercio. Gobierno de España. [online] Available at: http://www.idae.es/uploads/documentos/documentos_10737_Biomasa_Digestores_Anaerobios_A2007_0d62926d.pdf [Accessed 22 Mar. 2017], 1-48.

IETA (2017). Precios CO2. Sendeco2. International Emissions Trading Association [online] Available at: https://www.sendeco2.com/es/precios-co2 [Accessed 21 Dec. 2017].

International Energy Agency [IEA] (2009). *Energy Policies of IEA Countries. Spain 2009 Review*. Available at: https://www.iea.org/publications/freepublications/publication/spain2009.pdf [Accessed 28 Dec. 2016], 1-162.

Janczak, D., Dach, J., Bugala, A., Slowij, P. & Neugebauer, M. (2016). *Complex energetic systems: case analysis of connected greenhouse and biogas plant*. Book 4 Energy and Clean Technologies, 3, 243-249.

Jarauta, L. (2005). *Digestión anaerobia para el tratamiento de residuos orgánicos : estudio de las necesidades para la implantación en Perú*. Energía, 1-2.

Kantor, D. (2005). *El negocio de limpiar el aire*. Clarin.com. Argentina [online] Available at: http://edant.clarin.com/suplementos/economico/2005/03/27/n-00311.htm [Accessed 6 Feb. 2018].

Karwowski T., (1996). *Zasady eksploatacji i opłacalności zakupu maszyn*. IBMER, Warszawa, 4-8.

Karwowski T. (1998). *Polska w drodze do Unii Europejskiej. Zespołowe użytkowanie maszyn warunkiem unowocześnienia polskiego rolnictwa*. Przegl. Tech. Roln. Leśn, 1, 2-6.

Kivaisi, A.K. & Mtila M. (1998). *Production of biogas from water hyacinth in a two-stage bioreactor*. World J Microbiol Biotechnol, 14, 125-31.

Lee, M., Hidaka, T., Hagiwara, W. & Tsuno. H. (2009). *Comparative performance and microbial diversity of hyperthermophiclic and thermophilic co-digestion of kitchen garbage and excess sludge*. Bioresour. Technol., 100, 578-585.

Lewicki, A., Koz, K., Pietrowski, M., Zbytek, Z., Przyrodniczy, U., Instytut, P. & Rolniczych, I. M. (2016). *Methane fermentation of chicken droppings*, 61(4), 60-62.

López, J.C., Baille, A., Bonachela, S. & Pérez-Parra, J. (2008). *Analysis and prediction of greenhouse green bean (Phaseolus vulgaris L.) production in a Mediterranean climate*. Biosystems Engineering, 103(3), 344-356.

López, J. C., Pérez, C., Acien, F. G. (2016). *Residuos vegetales procedentes de los invernaderos de almería*. Fundación Cajamar. Departamento de Ingeniería. Universidad de Almería. Available at: https://www.cajamar.es/pdf/bd/agroalimentario/innovacion/formacion/actividades-de-transferencia/017-restos-vegetales-1466406472.pdf [Accessed 15 Dec. 2016], 1-9.

Wilken, D. (nd). El uso del biogás en Alemania. Condiciones político-legales, económicas y técnicas. [online]. Energy. Federal Ministry of Economics and Technology. Available at: http://www.ahkzakk.com/fileadmin/ahk_zakk/Events/Delegationsreise_EE_2012/Presentaciones_Infotag/Biogas.pdf [Accessed 15 Feb. 2017], 1-27.

Monforte, C. (2016). *Los precios del 'pool' eléctrico repuntan un 60% desde Abril*. Electronic Newspaper. Energía. Madrid: Spain.

Muzalewski, A. (2010). *Koszty eksploatacji maszyn. Wydawnictwo ITP*. Falenty – Warszawa. 1-25.

Página de Preciogas (2017). *Precio kWh gas natural*. [online] Available at: http://preciogas.com/conceptos/precio-kwh [Accessed 24 Feb. 2017].

Parra, S. (2004). *Análisis económico de la valoración de residuos agrícolas orgánicos*. Tesis doctoral. Escuela Politécnica Superior. Universidad de Almería, 1-206.

Przyrodniczy, U., Wydzia, P., Rozprawa, D. J., Promotor, J. D., & Pilarski, K. (2014). *Technologia wytwarzania biogazu z wykorzystaniem wybranych odpadów z produkcji i przetwórstwa warzyw*. Warszawa.

Qi X., Zhang S., Wang Y. & Wang R. (2005). A*dvantages of the integrated pig-biogas-vegetable greenhouse system in North China*. Ecological Engineering, 24, 177-185.

Ramesh, S. Jayanthi, S & Gandhimathi, S. (2008). *Feasibility study on anaerobic digestion of garbage using lime pretreatment.* Jr of Industrial Pollution Control. Department of Civil Engineering. National Institute of Technology, India, 24(2), 123-128 [online] Available at: http://www.icontrolpollution.com/articles/feasibility-study-on-anaerobic-digestion-of-garbage-using-lime-pretreatment-123-128.pdf [Accessed 8 Feb. 2017].

Ramos-Miras, J.J. (2002). *Estudio de la contaminación por metales pesados y otros procesos de degradación química en los suelos en los invernaderos del Poniente Almeriense*. Editorial Universidad de Almería, Tesis doctoral, Almería.

Sánchez-Guerrero, M. C., Lorenzo, P., Medrano, E., Castilla, N., Soriano, T. & Baille, A. (2005). *Effect of variable CO2 enrichment on greenhouse production in mild winter climates*. Agricultural and Forest Meteorology, 132, 244-252.

Sharma, S. K., Mishra, I. M., Sharma, M. P. & Saini, J. S. (1988). Effect of particle size on biogas generation from biomass residues. Department of Chemical Engineering. Department of Mechanical Engineering. University of Roorkee, India. Biomass (17), 251-263.

Tambone, F., Scaglia, B., D'Imporzano, G., Schievano, A., Orzi, V., Salati, S., & Adani, F. (2010). *Assessing amendment and fertilizing properties of digestates from anaerobic* *digestion through a comparative study with digested sludge and compost*. Chemosphere, 81(5), 577-583.

Tolón Becerra, A. & Lastra Bravo, X. (2010). *La agricultura intensiva del poniente almeriense. Diagnóstico e instrumentos de gestión ambiental*. M+A. Revista Electrónica de Medioambiente, 8, 1-22.

Trujillo, D., Perez, J. F. & Cebre, F.J. (1993). Energy recovery from wastes: anaerobic digestion of tomato plant mixed with rabbit wastes. *Bioresour Technol*, 45, 81-83.

Valera, D. L., Belmonte, L. J., Domingo, F., & López, A. (2014). *Los invernaderos de Almería. Análisis de su tecnología y rentabilidad*. Serie Economía. Fundación Cajamar Caja Rural, 1- 504.

Vítěz, T., Haitl, M., Karafi, Z., Mach, P., Fryč, J., Lošák, T., & Szostková, M. (2011). *Use of bio - enzymatic preparations for enhancment biogas production.* Volume LIX (3), 203-208.

Wang, G., (2010). *Biogas Production from Energy Crops and Agriculture Residues* (PhD). National Laboratory for Sustainable Energy. Riso-DTU, Technology University of Denmark, 1-89.